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Department of Interdisciplinary Studies (Human Kinetics, Nutrition, Health Promotion)

The University of British Columbia
Vancouver, Canada

Date Oct. 10/97

DE-6 (2/88)
Abstract

Physical activity and adequate calcium intake have the potential to increase peak bone mass and reduce the incidence of osteoporosis later in life. This study investigated the effects of 18-months of weight training and calcium supplementation on adolescent bone mineral and bone size and the bone remodeling transient.

After screening, 108 female volunteers, mean age 14.1 y, from 4 high schools were assigned to a non-exercise or exercise group, based on the school they attended. Exercise subjects were matched for weight, months past menarche and height to non-exercise subjects. Pairs were randomly given 1000 mg/d calcium supplement or placebo. Calcium and placebo pairs were matched to form blocks of 4 subjects forming 4 treatment groups: exercise/calcium (EC), exercise/placebo (EP), no exercise/calcium (NC), no exercise/placebo (NP).

The PRECEDE PROCEED model of health promotion program planning and evaluation was used to plan the intervention program. Exercise subjects strength trained, 3x/wk in 5 week cycles of 1 easy, 1 moderate, and 3 high intensity weeks. High intensity was 3 sets of 5-7 repetitions to fatigue. The non-exercising group was instructed to continue with their current activity level. Subjects recorded calcium/placebo intake, physical activity, weight training and menstrual cycles. Bone mineral content (BMC) and density (BMD) of whole body, hip and spine were measured using a Norland XR 26 dual-energy X-ray absorptiometer initially, and at 6 and 18 months. Strength tests, anthropometry, dietary, lifestyle and program compliance questionnaires were also completed.
Eighty-seven girls completed the study with a mean exercise and supplementation compliance of 48.3% and 75.8% respectively. Program drop-outs and poor compliance necessitated revision of subject sets to examine the effects in participants who had at least 50% program compliance. Repeated measures ANCOVA tested for changes across time and between groups, and ANCOVA tested for effects and interactions of calcium and exercise. Correlations with bone mineral changes and calculations of calcium retention efficiency were completed. Femoral neck and lumbar spine BMD were converted to bone mineral apparent density (BMAD) to account for bone size. Factors affecting program compliance were identified through rating scales.

Significant results between 0-6 mo., the bone remodeling transient period, were: i) interaction of calcium supplementation and weight training at the femoral neck indicating benefits of calcium in the no-exercise group ii) positive effect of calcium for lumbar spine BMD, iii) negative effect of exercise for total body and trochanter skeletal area, iv) total calcium intake was related to increases in femoral neck and lumbar spine BMD. From 6-18 mo., the true intervention period, significant results included: i) interaction of calcium supplementation and weight-training for femoral neck BMD indicating that calcium was beneficial in the exercise group ii) negative effect of calcium for lumbar spine BMD and area. Other significant results included greater increases in lower body strength and bicristal bone breadth in the exercise group, associations of maturation, weight change, and lean body mass change with changes in bone mineral measures, higher P values for BMAD results than for areal density results, negative association between calcium retention efficiency and maturation, and high calcium intake (>1200 mg/ vs. <600 mg/d) was associated with greater increases in total body BMD over the 18-months. Time, social
aspects and perceived health, fitness and aesthetic factors had the most influence on program compliance. In conclusion, this was the first study to investigate effects of the remodeling transient, main effects and interaction of calcium and exercise in a long-term intervention study of adolescent girls. Calcium-supplementation and weight-training were not successful in increasing bone mineral, bone size or skeletal area during the true intervention months. There was interaction between calcium and exercise at the femoral neck bone site and evidence of the bone remodeling transient. These results have implications for clinical and future research applications as well as in bone health education and promotion for teenage girls in an effort to optimize peak bone mass for osteoporosis prevention.
# Table of Contents

Abstract  
Table of Contents  
List of Tables  
List of Figures  
Acknowledgment  
Introduction  

Chapter 1. Review of Literature  

1.1 Overview  
1.2 Osteoporosis  
1.3 Bone Mineral Acquisition During Adolescence, Bone Remodeling and the Bone Remodeling Transient  

Introduction  
i) Bone Mineral Acquisition During Adolescence  
ii) Bone Remodeling  
iii) The Bone Remodeling Transient  
1.4 Bone Densitometry  
1.5 Factors Affecting Bone Mass  
i) Mechanical Loading and Physical Activity  
Animal Studies  
Unloaded Bone  
Body Weight  
Previous Physical Activity  
Athletes  
Unilateral Loading  
Weight-Bearing Activity  
Muscular Strength and Bone Mineral  
Studies of Adolescents  
Adolescents and Physical Activity  

ii) Nutritional Issues; Calcium and Calcium Supplementation  
Calcium Intake of Adolescents  
Calcium and Bone Accretion  
Dietary Influences on Calcium Absorption  
Calcium Supplementation and Bone Mineral
# Table of Contents continued

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-Sectional and Recall Studies</td>
<td>73</td>
</tr>
<tr>
<td>Intervention Studies</td>
<td>75</td>
</tr>
<tr>
<td>iii) Interaction Between Physical Activity and Calcium Intake</td>
<td>81</td>
</tr>
<tr>
<td>iv) Hormones</td>
<td>85</td>
</tr>
<tr>
<td>v) Smoking</td>
<td>90</td>
</tr>
<tr>
<td>vi) Heredity</td>
<td>93</td>
</tr>
<tr>
<td>1.6 Bone Size and Skeletal Area</td>
<td>96</td>
</tr>
<tr>
<td>1.7 PRECEDE PROCEED Model of Health Promotion Program Planning and Evaluation</td>
<td>98</td>
</tr>
<tr>
<td>i) Phase 1: Social Diagnosis</td>
<td>101</td>
</tr>
<tr>
<td>ii) Phase 2: Epidemiological Diagnosis</td>
<td>103</td>
</tr>
<tr>
<td>iii) Phase 3: Behavioural and Environmental Diagnosis</td>
<td>104</td>
</tr>
<tr>
<td>iv) Phase 4: Educational and Organizational Diagnosis</td>
<td>106</td>
</tr>
<tr>
<td>v) Phase 5: Administrative and Policy Diagnosis</td>
<td>108</td>
</tr>
<tr>
<td>vi) Phase 6: Implementation</td>
<td>108</td>
</tr>
<tr>
<td>vii) Phase 7-9: Evaluation</td>
<td>109</td>
</tr>
<tr>
<td>Phase 7: Process Evaluation</td>
<td>109</td>
</tr>
<tr>
<td>Phase 8: Impact Evaluation</td>
<td>110</td>
</tr>
<tr>
<td>Phase 9: Outcome Evaluation</td>
<td>110</td>
</tr>
<tr>
<td>1.8 Adherence to Exercise</td>
<td>111</td>
</tr>
<tr>
<td>Predisposing Factors</td>
<td>111</td>
</tr>
<tr>
<td>Enabling Factors</td>
<td>115</td>
</tr>
<tr>
<td>Reinforcing Factors</td>
<td>116</td>
</tr>
<tr>
<td>1.9 School-Based Health Promotion Programs</td>
<td>118</td>
</tr>
<tr>
<td>Chapter 2. Statement of the Problem</td>
<td>121</td>
</tr>
<tr>
<td>2.1 Objectives</td>
<td>121</td>
</tr>
<tr>
<td>2.2 General Hypothesis</td>
<td>122</td>
</tr>
<tr>
<td>Chapter 3. Methodology</td>
<td>123</td>
</tr>
<tr>
<td>3.1 Study Design</td>
<td>123</td>
</tr>
<tr>
<td>3.2 Subject and School Recruitment</td>
<td>124</td>
</tr>
<tr>
<td>3.3 Subject Selection</td>
<td>124</td>
</tr>
<tr>
<td>3.4 Initial Measurements</td>
<td>126</td>
</tr>
<tr>
<td>Bone Mineral Content and Density</td>
<td>127</td>
</tr>
<tr>
<td>Anthropometry</td>
<td>128</td>
</tr>
</tbody>
</table>
Table of Contents continued

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Dietary Information</td>
<td>131</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>Intervention Program Planning</td>
<td>131</td>
</tr>
<tr>
<td>3.6</td>
<td>Intervention Program</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td>Weight-Training Exercise Program</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td>Calcium Supplementation</td>
<td>136</td>
</tr>
<tr>
<td></td>
<td>Record Keeping</td>
<td>137</td>
</tr>
<tr>
<td></td>
<td>Incentive Program</td>
<td>138</td>
</tr>
<tr>
<td>3.7</td>
<td>Six-Month Measurements</td>
<td>138</td>
</tr>
<tr>
<td>3.8</td>
<td>Final Measurements</td>
<td>139</td>
</tr>
<tr>
<td>3.9</td>
<td>Analysis</td>
<td>139</td>
</tr>
<tr>
<td>3.10</td>
<td>Delimitations</td>
<td>143</td>
</tr>
<tr>
<td>3.11</td>
<td>Limitations</td>
<td>144</td>
</tr>
<tr>
<td>3.12</td>
<td>Specific Hypotheses</td>
<td>144</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>Results</td>
<td>146</td>
</tr>
<tr>
<td>4.1</td>
<td>Subject Set 1 Results (subjects who started the study)</td>
<td>146</td>
</tr>
<tr>
<td></td>
<td>Baseline Descriptives</td>
<td>146</td>
</tr>
<tr>
<td></td>
<td>Program Compliance</td>
<td>148</td>
</tr>
<tr>
<td>4.2</td>
<td>Subject Set 2 Results (subjects who completed the study)</td>
<td>148</td>
</tr>
<tr>
<td></td>
<td>Baseline Descriptives</td>
<td>148</td>
</tr>
<tr>
<td></td>
<td>Program Compliance, Calcium Intake, Strength Changes</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>Bone Mineral Changes</td>
<td>153</td>
</tr>
<tr>
<td>4.3</td>
<td>Revised Subject Sets</td>
<td>157</td>
</tr>
<tr>
<td>4.4</td>
<td>Subject Set 3 and 4 Results</td>
<td>158</td>
</tr>
<tr>
<td></td>
<td>Baseline Descriptives, Program Compliance, Strength Changes and Calcium Intake</td>
<td>158</td>
</tr>
<tr>
<td></td>
<td>Bone Mineral Changes</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>Bone Mineral Apparent Density (BMAD)</td>
<td>174</td>
</tr>
<tr>
<td></td>
<td>Total Calcium Intake and Bone Mineral Changes</td>
<td>181</td>
</tr>
<tr>
<td></td>
<td>Case Studies</td>
<td>186</td>
</tr>
<tr>
<td></td>
<td>Correlation Analysis Results</td>
<td>188</td>
</tr>
<tr>
<td></td>
<td>Skeletal Area and Bone Size Changes</td>
<td>196</td>
</tr>
<tr>
<td></td>
<td>Program Compliance Factors</td>
<td>201</td>
</tr>
<tr>
<td>4.5</td>
<td>Summary of Results</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td>General Hypothesis</td>
<td>204</td>
</tr>
<tr>
<td></td>
<td>Specific Hypotheses</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>Other Significant Results</td>
<td>209</td>
</tr>
</tbody>
</table>
Table of Contents continued

Chapter 5. Discussion 212
  5.1 Baseline Descriptives 212
  5.2 Program Compliance and Factors Affecting Compliance 212
  5.3 Bone Mineral Changes 215
    The Bone Remodeling Transient; 0-6 Months 220
    Main Effects During the True Intervention Period of 6-18 Months 226
  5.4 Total Calcium Intake and Bone Mineral Changes 237
  5.5 Interaction Between Physical Activity and Calcium 242
  5.6 Skeletal Area, Bone Size and Bone Mineral Apparent Density (BMAD) Changes 243

Chapter 6. Summary and Conclusions 246
  6.1 Summary 246
  6.2 Conclusions 248
  6.3 Implications 250
  6.4 Future Research 251

References 253

Appendices 278
  A. Certificates of Ethics Approval and School Board Approval 278
  B. Introductory Letter and Informed Consent 281
  C. Self-Rated Maturational Assessment 286
  D. Lifestyle Questionnaire 289
  E. Subject Matching Program 292
  F. Description of Measurement Procedures 293
  G. St. Paul's Hospital Nuclear Medicine Waiver 296
  H. DXA Printout 298
  I. 3-Day Dietary Record 305
  J. Food-Frequency Questionnaire 312
  K. PRECEDE PROCEED Model Application 315
  L. Weight-Training Program 325
  M. Program Questionnaire 327
  M - b. Program Questionnaire Results 330
  N. Weight-Training Record Sheet 333
  O. Physical Activity Record Instructions 336
  P. Incentive Program Summary 337

viii
<table>
<thead>
<tr>
<th>Table of Contents continued</th>
<th>page:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glossary</td>
<td>354</td>
</tr>
<tr>
<td>Biography</td>
<td>357</td>
</tr>
</tbody>
</table>

ix
### List of Tables

| Table 1.1 | Summary of Studies: Effects of Physical Activity on Adolescent Bone Mineral | 52 |
| Table 1.2 | Summary of Studies: Calcium Effects by Investigational Design Features | 59 |
| Table 1.3 | Summary of Calcium Intake Recommendations | 61 |
| Table 1.4 | Quality of Various Calcium Sources | 69 |
| Table 3.1 | Treatment and Control Groups | 123 |
| Table 4.1 | Baseline Descriptive Statistics (subject set 1, n=108) | 147 |
| Table 4.2 | Baseline Descriptive Statistics (subject set 2, n=87) | 149 |
| Table 4.3 | Program Compliance (subject set 2, n=87) | 151 |
| Table 4.4 | Calcium Intake (subject set 2, n=87) | 151 |
| Table 4.5 | Pre and Post Strength Measures and Changes (subject set 2, n=87) | 151 |
| Table 4.6 | Subject Changes 0-6 Months (subject set 2, n=87) | 154 |
| Table 4.7 | Subject Changes 6-18 Months (subject set 2, n=87) | 155 |
| Table 4.8 | Subject Changes 0-18 Months (subject set 2, n=87) | 156 |
| Table 4.9 | Baseline Descriptive Statistics (subject set 3, n=50) | 159 |
| Table 4.10 | Baseline Descriptive Statistics for Matched Blocks (subject set 4, n=28) | 160 |
| Table 4.11 | Program Compliance (subject set 3, n=50) | 161 |
| Table 4.12 | Program Compliance (subject set 4, n=28) | 161 |
| Table 4.13 | Strength Measures and Changes (subject set 3, n=50) | 162 |
| Table 4.14 | Pre to Post Strength Changes (subject set 4, n=28) | 162 |
| Table 4.15 | Calcium Intake (subject set 3, n=50) | 163 |
| Table 4.16 | Calcium Intake (subject set 4, n=28) | 163 |
| Table 4.17 | Subject Changes 0-6 Months (subject set 3, n=50) | 165 |
| Table 4.18 | Subject Changes 0-6 Months (subject set 4, n=28) | 166 |
| Table 4.19 | Subject Changes 6-18 Months (subject set 3, n=50) | 167 |
| Table 4.20 | Subject Changes 6-18 Months (subject set 4, n=28) | 168 |
| Table 4.21 | Subject Changes 0-18 Months (subject set 3, n=50) | 169 |
| Table 4.22 | Subject Changes 0-18 Months (subject set 4, n=28) | 169 |
| Table 4.23 | Summary of P values for Interactions and Main Effects of Exercise and Supplemented Calcium On Bone Mineral Changes (subject set 3, n=50 and 4, n=28) | 173 |
| Table 4.24 | Calcium Retention Efficiency of Case Studies | 185 |
| Table 4.25 | Percent Changes in Case Studies | 185 |
| Table 4.26 | Summary of Significant Factors Correlating to Bone Mineral Changes (subject set 3, n=50) | 189 |
| Table 4.27 | Summary of Strength and Lean Body Mass Change Correlations to Bone Mineral Changes (subject set 3, n=50) | 197 |
List of Tables continued

<table>
<thead>
<tr>
<th>Table 4.28</th>
<th>Skeletal Area Changes (subject set 3, n=50, subject set 4, n=28)</th>
<th>199</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 4.29</td>
<td>Summary of P values for Interactions and Main Effects of Exercise and Calcium Supplementation on Skeletal Area and Bone Size Changes (subject set 3, n=50, subject set 4, n=28)</td>
<td>200</td>
</tr>
</tbody>
</table>
List of Figures

<table>
<thead>
<tr>
<th>Figure Number</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Bone Mineral Content Growth and Growth Velocity</td>
<td>11</td>
</tr>
<tr>
<td>1.2</td>
<td>Bone Remodeling</td>
<td>16</td>
</tr>
<tr>
<td>1.3</td>
<td>Error in Areal Bone Mineral Density</td>
<td>24</td>
</tr>
<tr>
<td>1.4</td>
<td>PRECEDE PROCEED Model</td>
<td>99</td>
</tr>
<tr>
<td>1.5</td>
<td>Phases 1, 2, and 3 of the PRECEDE Model</td>
<td>102</td>
</tr>
<tr>
<td>1.6</td>
<td>Steps for Behavioural and Environmental Diagnosis</td>
<td>105</td>
</tr>
<tr>
<td>1.7</td>
<td>Rating Table to Target Factors for Intervention</td>
<td>106</td>
</tr>
<tr>
<td>1.8</td>
<td>Phases 4 and 5 of the PRECEDE Model</td>
<td>107</td>
</tr>
<tr>
<td>3.1</td>
<td>Lumbar Spine DXA Scan Position</td>
<td>129</td>
</tr>
<tr>
<td>3.2</td>
<td>Proximal Femur DXA Scan Position</td>
<td>129</td>
</tr>
<tr>
<td>4.1</td>
<td>Trochanter BMD Change With Time (subject set 4, n=28)</td>
<td>171</td>
</tr>
<tr>
<td>4.2</td>
<td>Femoral Neck BMD Change With Time (subject set 4, n=28)</td>
<td>171</td>
</tr>
<tr>
<td>4.3</td>
<td>L2-L4 BMD Change With Time (subject set 4, n=28)</td>
<td>172</td>
</tr>
<tr>
<td>4.4</td>
<td>Total Body BMD Means for Treatment Groups (subject set 4, n=28)</td>
<td>175</td>
</tr>
<tr>
<td>4.5</td>
<td>Total Body BMC Means for Treatment Groups (subject set 4, n=28)</td>
<td>175</td>
</tr>
<tr>
<td>4.6</td>
<td>Femoral Neck BMD Means for Treatment Groups (subject set 4, n=28)</td>
<td>176</td>
</tr>
<tr>
<td>4.7</td>
<td>Trochanter BMD Means for Treatment Groups (subject set 4, n=28)</td>
<td>176</td>
</tr>
<tr>
<td>4.8</td>
<td>Lumbar Spine L2-L4 BMD Means for Treatment Groups (subject set 4, n=28)</td>
<td>177</td>
</tr>
<tr>
<td>4.9</td>
<td>Total Body BMC Change 0-6 Months (subject set 4, n=28)</td>
<td>178</td>
</tr>
<tr>
<td>4.10</td>
<td>Femoral Neck BMAD Change 0-6 Months (subject set 4, n=28)</td>
<td>180</td>
</tr>
<tr>
<td>4.11</td>
<td>Lumbar Spine L2-L4 BMAD Change 6-18 Months (subject set 4, n=50)</td>
<td>180</td>
</tr>
<tr>
<td>4.12</td>
<td>Suggestion of a Threshold Effect of Calcium</td>
<td>183</td>
</tr>
<tr>
<td>4.13</td>
<td>Correlation Between Calcium Retention Efficiency and Maturation</td>
<td>184</td>
</tr>
<tr>
<td>4.14</td>
<td>Correlation Between Total Calcium Intake and Femoral Neck BMD Change 0-6 Months</td>
<td>190</td>
</tr>
<tr>
<td>4.15</td>
<td>Correlation Between Exercise Compliance and Femoral Neck BMD Change 0-6 Months</td>
<td>191</td>
</tr>
<tr>
<td>4.16</td>
<td>Correlation Between Total Calcium Intake and Lumbar Spine L2-L4 BMD Change 0-6 Months</td>
<td>192</td>
</tr>
<tr>
<td>4.17</td>
<td>Correlation Between Exercise Compliance and Lumbar Spine L2-L4 BMD Change 0-6 Months</td>
<td>193</td>
</tr>
<tr>
<td>4.18</td>
<td>Correlation Between Maturation and Total Body BMC Change 6-18 Months</td>
<td>194</td>
</tr>
</tbody>
</table>
## List of Figures continued

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 4.19</td>
<td>Correlation Between Change in Body Weight and Total Body BMC Change 6-18 Months</td>
<td>195</td>
</tr>
<tr>
<td>Figure 4.20</td>
<td>Total Body Bone Area Change 0-6 months (subject set 4, n=28)</td>
<td>200</td>
</tr>
<tr>
<td>Figure 5.1</td>
<td>Variation in Subjects: Total Body BMC Change 6-18 Months Plotted Against Maturation (subject set 3, n=50)</td>
<td>218</td>
</tr>
<tr>
<td>Figure 5.2</td>
<td>Bone Mineral Content Growth and Growth Velocity</td>
<td>219</td>
</tr>
<tr>
<td>Figure 5.3</td>
<td>Body Composition Percent Change 0-6 Months (subject set 4, n=28)</td>
<td>223</td>
</tr>
<tr>
<td>Figure 5.4</td>
<td>Change in Growth and Total Body Bone Mineral Variables 0-6 Months (subject set 4, n=28)</td>
<td>224</td>
</tr>
<tr>
<td>Figure 5.5</td>
<td>Body Composition Percent Change 6-18 Months (subject set 4, n=28)</td>
<td>228</td>
</tr>
<tr>
<td>Figure 5.6</td>
<td>Change in Growth and Total Body Bone Mineral Variables 6-18 Months (subject set 4, n=28)</td>
<td>229</td>
</tr>
</tbody>
</table>
Acknowledgment

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Introduction

Osteoporosis is a chronic disease characterized by low bone mass and microarchitectural degeneration which manifests as low trauma fractures, typically of the forearm, hip and spine, mostly in aging women (Gordon and Huang, 1995; Woolf and Dixon, 1988). In Canada, hip fractures resulting from osteoporosis are at epidemic proportions, and it has been estimated that they will increase by 72.8% from 1987 to 2006 (Martin et al., 1991). This has tremendous impact on quality of life as well as health care costs (Barrett-Connor, 1995). Data on the health care cost of osteoporosis in Canada are sparse but as an indicator, the United States spent 11 billion dollars in 1995 on health care expenditures related to osteoporotic fractures in women (Ray et al., 1997). Preventive measures could be important for decreasing health care expenditures for osteoporosis.

Bone mineral density, assessed by dual-energy X-ray absorptiometry (DXA), is currently the best biological predictor of bone strength and osteoporotic fracture (Wasnich, 1993). Most fractures result from falls, but not all falls result in fractures, and of the people that do fall DXA provides the best predictor of fracture (Johnston and Slemenda, 1993; Heaney, 1992; Wasnich, 1993; Meunier, 1993). Bone mass is, at any age, the peak bone mass minus bone loss. Most interventions are aimed at slowing or eliminating this bone loss, for example using hormone replacement therapy (Lindsay, 1993). However, research interests are now focusing on the period of skeletal development as a possible intervention time for the prevention of fractures later in life (Fassler and Bonjour, 1995; Mikhail, 1992). The majority of total adult bone mass is accumulated during adolescence, therefore, examining the factors which could increase peak bone mass of the young adult is of value, especially since few
longitudinal intervention studies have been done in this area. In adults, research suggests that weight bearing physical activity can increase bone mineral density and/or slow bone loss. Cross-sectional studies have revealed that people who engage in weight training and weight-bearing sports have a higher bone density than those involved in endurance and non weight-bearing activities. Intervention studies with calcium supplementation have provided some convincing evidence that adequate calcium intake may be a means to slow bone loss in adults and elderly (Fujita, 1996; Heaney, 1991 and 1992; Hegsted, 1986; King, 1994).

Poor diet and eating habits, inactivity, smoking and substance abuse have been identified as significant contributors to numerous health problems, including osteoporosis. These are habits observed in young females. For example, fewer than 10% are involved in 30 minutes or more of aerobic exercise every other day (Stephens and Craig, 1990), the incidence of smoking in teenage girls continues to increase (Greaves, 1987; Lawrence, 1996; Tonkin, 1994), 6-20% of adolescent girls reported disordered eating behaviors (McVey, 1994), and many do not get enough calcium or other essential nutrients (Barr, 1994; Whiting et al., 1995) and choose poor snacks (Frederick and Hawkins, 1992; Mesters and Oostveen, 1994).

The amount and type of exercise, the amount of calcium, the interaction between these two factors, and their effects on bone gain during adolescence are still unclear. These factors need to be investigated further and the results communicated to adolescent girls through well planned health education programs to help improve their quality of life, and potentially reduce osteoporosis. Schools provide an excellent means for reaching the majority of children and adolescents to educate them about health, and to facilitate their
development and adoption of healthy lifestyle habits. However, many school-based health education and promotion programs have been unsuccessful in doing so partly because they have failed to follow evidence-based planning guided by systematic application of social and behavioral science theories (Green and Kreuter, 1991). Adoption of healthful lifestyle habits during youth could have a great impact on the prevention of chronic diseases, such as osteoporosis, and in enhancing quality of life.
Chapter 1. Review of the Literature

1.1 Overview
The definition, risk factors, possible causes and treatments, measurement, as well as the recent research focus of osteoporosis will be described. The topics of bone mineral acquisition and remodeling, the hereditary contribution to bone mass and possible lifestyle factors affecting the attainment of peak bone mass will be reviewed. Specifically, studies investigating the effects of physical activity and nutrition-related factors on bone mass in adults, and more importantly adolescents, will be a strong focus of the review. This will help clarify what is known and what still needs to be determined regarding the impact of these factors on the developing skeleton and their role in osteoporosis prevention. Finally, a health promotion planning model and its use in planning school programs will be reviewed as a possible means of developing activity programs for the purpose of osteoporosis prevention.

1.2 Osteoporosis
"Osteoporosis is a disease characterized by low bone mass, microarchitectural deterioration of bone tissue leading to enhanced bone fragility and a consequent increase in fracture risk" (Gordon and Huang, 1995). It is typically a disease observed in elderly women due to a progressive bone loss, beginning as early as the third decade in life, and continuing throughout life with an accelerated phase in the decade following menopause (Francis, 1990). Bone fractures, and their consequent pain and disability, are the most severe manifestations of osteoporosis, with the most common fracture sites being the forearm, hip and spine, and less often the ribs and pelvis (Martin, 1995). Though some bone loss is a normal consequence of aging, accelerated loss leading to osteoporosis is caused by the complex interaction of genetics, hormones, exercise, nutrition,
Body weight and disease (Francis, 1990; Riggs and Melton, 1988). Well publicized risk factors for osteoporosis reflect the importance of these factors:

- Inherited low bone weight and small structure, family history of osteoporosis
- Insufficient regular exercise, complete inactivity or prolonged immobility
- Hypoestrogenic states such as menopause, amenorrhea, early menopause or late menarche
- Nutritionally inadequate diets, low calcium and vitamin D intakes
- Excessive intake of tobacco or caffeine
- Chronic use of certain medications such as corticosteroids
- Diseases such as those of the kidneys, liver, thyroid, gastrointestinal tract, and rheumatoid arthritis (Gordon et al., 1995).

Bone is a dynamic tissue continually being remodeled; that is, the processes of bone resorption and new bone formation are ongoing. Resorption and formation are closely linked for the purpose of maintaining bone mass. With increased age these processes become imbalanced in favor of resorption and thus result in a net bone loss (Gordon et al., 1995). The onset of osteoporosis mostly occurs in women within 5-15 years after menopause because of decreased circulating estrogen and a consequent increase in bone turnover and resorption (Gordon et al., 1995).

In general terms, the etiologic factors contributing to osteoporosis can be summarized as i) failure to achieve peak bone mass while growing, ii) failure to maintain bone mass through adulthood and, iii) an increased rate of bone loss in elderly years (Martin and Bailey, 1993). Men tend to be at a lesser risk than women as they have a higher peak bone mass and have a slower rate of bone
loss (Gordon et al., 1995). It is estimated that 50% of women and 1 in 4 men over the age of 70 in Canada will suffer from osteoporosis (Gordon et al., 1995). This high lifetime incidence rate combined with the impact on health care costs and quality of life, has put osteoporosis at the forefront of health research and public health concern (Fassler et al., 1995). As the life span has increased so has osteoporosis because fracture risk increases exponentially with age (Gordon et al., 1995), with hip fracture risk doubling every six years after the age of fifty in both men and women (Martin et al., 1991).

Osteoporosis is clinically diagnosed when bone mineral density is 2.5 standard deviations below the mean for young healthy adults (Kanis, 1990; Kanis et al., 1994). For every standard deviation decrease in bone mineral density the risk of fracture nearly doubles (Hui, 1989; Johnston and Slemenda, 1993; Kanis et al., 1994; Wasnich, 1993). Bone mineral density is most often measured by a non-invasive technique called dual-energy X-ray absorptiometry (DXA) which measures bone mineral content (g) in a region of interest to yield an areal bone density (g/cm²). Body composition, including fat, bone mineral and bone mineral free lean mass, can also be measured through DXA. Other techniques, such as magnetic resonance imaging (MRI), computerized tomography (CT) and ultrasound, have also been used but have limitations: they are not as well validated, are expensive, or they include greater risks, such as high radiation exposure (Gordon et al, 1995; Johnston and Slemenda, 1993).

Research into osteoporosis includes not only a treatment-oriented focus, but also a more preventative focus. There are now accepted drug therapies for osteoporosis such as bisphosphonates (Rosen, 1995), alendronate, and calcitonin as well as hormone replacement therapy, which have been used to help slow
bone loss or build bone after loss in elderly individuals (Lindsay, 1993). These drugs mostly attempt to reduce the resorption of bone. Estrogen replacement therapy in women is a well-established and effective therapy for slowing bone loss, but it is limited to perimenopausal and postmenopausal women and may be associated with an increased cancer risk (Lindsay, 1992 and 1993).

Hereditary influence may account for a large portion of the variance in bone mineral density. For example, one study concluded that 46-62% of variance in bone mineral density was attributable to heredity (Krall and Dawson-Hughes, 1993). However, research focused on prevention has provided evidence that lifestyle factors, such as weight-bearing activity, adequate calcium intake, not smoking and minimizing caffeine and alcohol intake may be significant factors in optimizing peak bone mass and in maintaining it through adult life (Gordon, 1995; Heaney, 1992; Smith, 1995). Recent research has focused on gaining a greater understanding of bone acquisition during childhood and adolescence, the role of genetics, bone remodeling, and the interaction of lifestyle factors, with the goal of preventing this public health concern (Matkovic, 1992).

1.3 Bone Mineral Acquisition During Adolescence, Bone Remodeling and the Bone Remodeling Transient

Introduction:
To clearly understand the mechanisms of bone growth and remodeling it is necessary to understand the different types of bone, its components, structure and properties. Bone is a hard connective tissue which presents itself in different sizes and shapes to form the axial and appendicular skeletons. The functions of bone are to protect organs, maintain mineral homeostasis, and
provide a framework for locomotion and other movements. Bone is predominantly made up of collagen fibers and minerals, with the collagen fibers giving bone an elastic quality allowing them to bend and not break (Van de Graaf and Fox, 1992). The calcium-phosphate based mineral, hydroxyapatite, is deposited in the organic matrix, providing rigidity and strength. Calcium makes up about 32.2% of the mineral content of bone and phosphorus, along with other trace minerals comprise the rest (Bailey et al., 1996; Van de Graaf and Fox, 1992). There are two types of bone. Spongy or trabecular bone, making up 20-25% of the skeleton, has many thick vertical plates with finer interlacing horizontal plates, which together form the matrix (Haywood, 1986). This type of bone is found within the vertebrae, flat bones, and ends of long bones (Van de Graaf and Fox, 1992). Trabecular bone is strongest when there are many connections between the plates and when the plates are thicker.

The second type of bone, cortical bone, making up 75-80% of the skeleton, is hard and compact. It is found within the shafts of long bones and forms the hard shell of all bones (Vaughan, 1975). Cortical, or compact bone, is organized in units of tightly-woven circles around a central canal which brings blood and nourishment to the bone cells.

Bone mass is a term used loosely to refer to mineral content or density of bones. Bone mass, however, cannot currently be measured in vivo, but bone mineral content and density can be determined with high accuracy and precision. Bone mineral content is the amount of mineral, measured in grams, in a certain projected area of bone. Bone mineral density (g/cm^2) is the amount of bone mineral divided by the projected area of bone.
Bone growth follows a definite pattern and time schedule (Haywood, 1986). Specialized cells, the osteoblasts, are responsible for laying down new bone, and other cells, the osteoclasts, are responsible for resorption of bone. Bone growth is controlled by hormones, genetics, vitamins, minerals and other environmental factors (Vaughan, 1975). The skeleton continues to grow until about 18-20 years of age, but in females most epiphyseal plates are fused by the age of sixteen and skeletal growth is essentially completed (Haywood, 1986). During growth, or modeling, formation predominates over resorption resulting in increases in size and density and changes in shape of bone (Martin and McCulloch, 1987; Vaughan, 1975; Wolff, 1986). Trabecular bone responds to growth or other osteogenic stimulus by the plates becoming thicker, whereas cortical bone responds through the predominance of periosteal formation over endosteal resorption, resulting in increased cortical thickness. The greater the width of a bone the stronger it is and the more able it is to resist bending and breaking (Bailey et al., 1996; Heaney, 1993).

After the skeleton has completed linear growth, it is constantly under the influence of the remodeling process to eliminate old bone through resorption and to lay down new bone (Heaney, 1993). This continuous process of bone turnover can result in no change, a net gain or a net loss in bone mass. This bone-remodeling balance is in part a consequence of the stress of the mechanical loads placed on it (Vaughan, 1975; Wolff, 1986), as well as the influence of hormones, nutrients, and drugs, e.g., those ones used in the treatment of osteoporosis. Increased loading on the bone (even after linear growth is complete) causes hypertrophy of bone and architectural reorganization so it can withstand the new load (Heaney, 1993). Unloading promotes resorption of bone, increases its porosity, decreases its strength, and thus makes it more prone
to fractures (Martin and McCulloch, 1987). Bone responds specifically to the mechanical strain resulting from the load placed on it. Strain is defined as the amount of deformation of bone per unit of length of the bone under load, and is therefore unitless. Bone growth, specifically bone acquisition during adolescence, and bone remodeling are described in detail in the following sections.

i) Bone Mineral Acquisition During Adolescence

The pattern of bone mineral acquisition follows a growth-curve pattern that is similar to other growth variables such as height and weight (Bailey et al., 1996; Malina and Bouchard, 1991), and is highly related to events during puberty (Bailey et al., 1997; Gordon et al., 1991; Grimston et al., 1992; Krabbe et al., 1979; Rubin et al., 1993). The majority of bone mineral, at least 90%, is laid down by the end of the rapid growth phase of adolescence (Bailey et al., 1996; Parfitt, 1994). This provides reason for investigating the potential of maximizing peak bone mineral during this time as bone acquisition during adolescence may be an important determinant of subsequent osteoporotic risk (Bonjour, 1991; Lloyd et al., 1992). Bone mineral content increases steadily during childhood, as does height and weight, then accelerates during adolescence (figure 1.1) and slows into adulthood (DePriester et al., 1991). Bone mineral content velocity peaks approximately one year after peak height velocity in both boys and girls and at about the time of menarche in females (Bailey et al., 1997; Krabbe et al., 1979; Malina and Bouchard, 1991; Tanner, 1990). Bailey et al. (1996) indicated that total body bone mineral content more than doubles between the ages of 8 and 15 years, and more specifically, 30% of lumbar and total body and 20% of femoral neck bone mineral content was accumulated during the three years around peak
Figure 1.1 Bone Mineral Content Growth and Peak Bone Mineral Accrual
(Martin et al., 1997)

height velocity. Kreipe (1995) reported that 45% of adult skeletal mass is accumulated during puberty. Bone mineral acquisition slows greatly after this time but continues into early adulthood even though maximal height has been attained by about age 16 in girls (Bailey et al., 1996; Bonjour et al., 1991; Matkovic et al., 1994). Ninety percent of adult height is attained by the age of peak height velocity but only 60-70% of adult bone mineral content, depending on site, was attained by peak bone mineral accrual velocity (Bailey et al., 1996). Mean peak bone mineral accrual velocity has been measured cross-sectionally in
girls to be 240 g/y (Martin et al., 1997). No definitive study has determined when peak bone mass occurs but the general agreement is between the ages of 20 and 30 years.

In another cross-sectional study (Lloyd et al., 1992) premenarcheal females, ages 10.7 - 13.3 years, attained 90% of adult height, 68% of adult weight, 83% of total body bone mineral density, and 53% of total bone mineral content, when compared to normative reference data for adults. Bonjour et al. (1991) reported that peak bone mineral density, measured by DXA, was achieved in 14-15 year olds at the spine and femoral neck (99.2% and 105.1%, respectively) and in the 17-18 year olds at the femoral shaft (99.1%), in comparison to reference data for 20-35 year olds. Gordon et al. (1991) reported no increases in lumbar spine bone mineral content in females after puberty. Slemenda et al. (1993) also demonstrated that skeletal mineralization during puberty accelerated and that 1/3 of the adult values for lumbar spine bone mineral content accumulated around the three years of the onset of puberty. Theintz et al. (1992) reported that the rate of bone mineral content and density accumulation was pronounced over a three-year period between 11-14 years then fell dramatically after the age of 16 years in the lumbar spine and femoral neck.

The rapid gain in skeletal volume around peak height velocity, combined with the one year delay until peak bone mineral accrual, results in a transient period of relative bone weakness (Parfitt, 1994), which may explain the higher fracture rates around peak height velocity in adolescents (Bailey et al., 1989; Blimkie et al., 1993). The need for calcium increases during peak height velocity to keep up with the increasing volume of the skeleton. Parfitt (1994) has hypothesized that calcium is borrowed from endosteal cortical surfaces to support the increasing
length of the bone. Rubin et al. (1993) reported a significant positive effect of calcium intake and physical activity on axial bone mineral density during this growth period suggesting, perhaps, that a higher calcium intake and increased physical activity would lessen cortical porosity (Parfitt, 1994).

The rate of bone mineral accrual is strongly associated with menarche as peak bone mineral accrual and menarche occur at approximately the same age (Bailey et al., 1997). Bonjour et al. (1991) observed an increase in gain of bone mineral density at all bone sites and in lumbar spine bone mineral content during the first two years postmenarche followed by a sharp reduction in accrual rate 2-4 years after menarche. Parfitt (1994) summarized a study which reported that lumbar bone mass accelerated between Tanner stages 3-5 of breast and pubic hair development, during which menarche typically occurs. Regular menstrual cycles after the onset of menarche provide levels of circulating estrogens which help in the feedback system indirectly affecting serum calcium levels and thus the amount of calcium in bone. When serum calcium is low, parathyroid hormone is secreted which draws calcium out of the bone and into the blood. Estrogen helps blunt this effect of parathyroid hormone and increases absorption of calcium from the gut to increase retention of calcium in the bone. Krabbe et al. (1979) noted that boys who experienced delayed puberty did not have the accelerated increases in height or bone mineral accrual. Delayed menarche in females, as often seen in highly-trained endurance athletes, then could have negative implications for attainment of peak bone mass. Growth is under the influence of sex and growth hormones with the axial skeleton and trabecular bone being more sensitive to estrogen and cortical bone being more dependent on growth hormone (Vaughan, 1975).
Cortical bone grows by periosteal apposition and cancellous or trabecular bone grows by endochondral ossification. The process of bone growing in length and width by new bone being laid down is called modeling (Parfitt, 1994). More specifically it can be described as the persistence of bone formation or resorption at the same location on the bone. This results in changes in the location of bone on the bone surfaces. The changes in locations are called formation drifts, where bone is being laid down on the periosteal surface, and resorption drifts, where bone is being eroded from the endosteal surfaces. Modeling is the principal mode of turnover in young bone. As growth continues, slows, and eventually ceases, bone becomes better organized to meet its stresses and remodeling becomes the principal mode of turnover (Parfitt, 1994).

ii) Bone Remodeling

Remodeling is a dynamic process which increases during puberty and continues through life in order to replace old bone with new. It is a normal process mediated by different factors which either speed it up, slow it down, favor resorption, or favor formation, resulting in a net gain or loss of bone (Frost, 1964).

A primary difference between modeling and remodeling is that in remodeling the osteoblasts are confined to a certain spot on the bone surface for a short period of time, whereas in modeling osteoblast recruitment to lay down new bone is located at the same spot over many years (Parfitt, 1994). Bone turnover is a process by which bone adapts to growth and the loads, stresses and strains it experiences throughout life. Carter et al. (1992) explained this process of bone adaptation by Wolff's Law which states that bone changes its internal architecture and external geometry based on the stresses it is put under. During
growth, remodeling balance is positive as bone mineral increases, whereas, during later adulthood, remodeling balance is often negative resulting in decreased bone mineral. Bone mass is a reflection of the balance between bone resorption and formation over time (Lanyon, 1996). Bone turnover increases substantially during puberty as indicated by urinary excretion of hydroxylysyl and lysyl-pyridinoline, suggesting resorption, and increased serum osteocalcin, suggesting bone formation (Parfitt, 1994). A positive remodeling balance during this time is crucial for optimal bone mineral accrual and investigation into factors affecting bone remodeling, such as calcium and mechanical loading, are necessary to ensure this (Matkovic et al., 1994).

Remodeling occurs in units, which are a collection of cells on the bone surface where the activity of resorption or formation, but never both at the same time, occur. Many bone-remodeling units, which vary in size, can be active in different phases of remodeling at one time (Frost, 1964). There are five basic phases of remodeling which include the resting phase (quiescence), resorption, completion of resorption, formation (repair), and formation complete (figure 1.2) (Peck and Avioli, 1988; Frost, 1964).

Remodeling is initiated by osteoclastic bone resorption where osteoclasts degrade both inorganic and organic materials (mineral and collagen) of the bone matrix (Teitelbaum, 1993). When resorption is complete, after about three weeks (Heaney, 1994) small cavities are left in the bone surface. The sum of all cavity volumes for the whole skeleton is termed the remodeling space, and the number of units active at one time, and their turnover rate, dictate the amount of bone deficit. If some influence has increased activation, i.e., the number of active
1. Resting Phase
A bone surface is covered by a protective layer of bone cells—called lining cells.

2. Resorption
During resorption, osteoclasts invade the bone surface and erode it, dissolving the mineral and the matrix.

3. Resorption Complete
A small cavity is created in the bone surface—resorption is complete.

4. Formation–Repair
Bone forming cells called osteoblasts begin to fill in the cavity with new bone.

5. Repair Complete
Finally, the bone surface is completely restored.

During formation osteoblasts form the new matrix and mineralization takes place filling in the cavities left by the osteoclasts (Peck and Avioli, 1988; Frost, 1964). After about 17 weeks primary ossification to 75% of full mineral component is complete, but
secondary mineralization to 95% of full mineral component takes about another 20 weeks (Heaney, 1994). When formation is complete, quiescence returns and the bone surface is covered by a protective layer of bone lining cells (Peck and Avioli, 1988). Completion of one remodeling cycle takes about 40 weeks, but is much quicker in adolescence, closer to six months, because of the increased turnover rate and growth influences (Heaney, 1994). The variation in the length of a remodeling cycle between adults and adolescence occurs during the osteoblast (formation) phase.

Different influences such as hormones, drugs, and lifestyle variables can affect the number of remodeling units activated as well as the rate of remodeling. A change in the activation frequency of new remodeling units initiates a remodeling transient where the bone remodeling space is affected. This has important implications for measuring the effect of any intervention (Heaney, 1994).

iii) The Bone Remodeling Transient

Heaney (1994) carried out a computer simulation of the bone remodeling transient, based on data gathered from histomorphometry and calcium-tracer kinetic studies. He developed a mathematical model to estimate the remodeling space for any given rate of remodeling. Any intervention, whether it is effective in changing bone mass or not, will alter the remodeling space and thus the true effect of an intervention must be measured from a baseline at the end of one remodeling cycle after the introduction of an intervention (Heaney, 1994).

Though the concept of the remodeling transient is accepted it is most often ignored while interpreting changes in bone mineral in treatment studies, or is
explained as part of how bone responds to a pharmacological intervention (Heaney, 1994). It has not been considered in any published studies of exercise or calcium intervention in adults or adolescents.

Increased calcium intake alters the frequency of activation by reducing parathyroid hormone (PTH) and thus decreasing the activation frequency. With fewer units undergoing resorption the transient period would therefore result in increased bone mineral content. If the calcium supplementation is withdrawn the temporary benefit will be lost, i.e., the remodeling space will, after one cycle, revert to the previous level. Calcium supplementation would not affect the remodeling balance in the long term unless it was continued past the transient period. Therefore, if calcium intake remained high bone loss could slow because the remodeling space would continue to reduce (Heaney, 1994). In the computer model, as calcium intake rose close to or above 2000 mg/d the effect on changing remodeling rate decreased.

In the case of intervening with increased mechanical loading, e.g., an exercise program, the remodeling rate is influenced by the distribution of the dynamic error strains throughout the bone tissue (Lanyon, 1996). The result during the remodeling transient is an increase in the number of units activated, therefore, increasing the remodeling space and decreasing the total bone mineral content during this time. However, if osteogenic strains of high magnitude and unusual distribution, are maintained past the transient they will stimulate recruitment and synthesis of osteoblasts to result in greater bone formation and net gain (Lanyon, 1996). Chillibeck et al. (1995) explained that increased strain induces increased bone formation by either depression of the osteoclasts and enhancing osteoblast synthesis. Prostaglandin release, generation of electric potential,
increased blood flow and microdamage in the central canal of bones may be the mechanisms of transferring the mechanical loading stimuli to signals for new bone formation (Chillibeck et al., 1995). Forwood and Burr (1993) also indicated that bone's response to exercise may depend on it's sensitivity to circulating growth and sex hormones.

Estrogen suppresses activation of remodeling units, therefore, estrogen withdrawal, as in postmenopausal women, would increase the remodeling space (Heaney, 1994). Estrogen withdrawal combined with the common pattern of decreased physical activity in elderly persons, results in a negative remodeling balance, which over the long term results in osteoporosis. The decreased intensity and diversity of loading resulting from a decline in physical activity is perceived by the bone as strain of low magnitude, low rate and of normal distributions and thus would not produce an osteogenic response, but rather increase resorption (Lanyon, 1996). Strains may have to be greater during menopause to offset the negative effects of estrogen withdrawal to achieve neutral or positive remodeling balance.

The effects of the remodeling transient make it necessary to separate out this period from the rest of the duration of the intervention in order to more accurately determine the effectiveness of an intervention (Heaney, 1994). This phenomenon will be considered in the design of the study reported here.

1.4 Bone Densitometry

Bone densitometry provides a means to non-invasively measure bone mineral density and content for clinical purposes such as screening for osteoporosis. Single photon absorptiometry (SPA), dual photon absorptiometry (DPA),
quantitative computed tomography (QCT), and dual-energy X-ray absorptiometry (DXA) are the most common methods, however, the first two are used much less frequently now with the development of the latter more advanced techniques. The underlying basis of these techniques is differential absorption of radiation by bone and the measurement of attenuation, which is directly related to the amount of bone mineral present, by calibration against a phantom of known density (Wahner et al., 1983). More recently, ultrasound techniques have also been introduced for screening purposes but are not as well validated as the other techniques (Gluer, 1995). Ultrasound works on very different principles than absorptiometry and QCT and because of its limitations will not be discussed in this review.

SPA was developed in 1963 to measure bone mineral content and density at cortical sites of appendicular bones (Wahner et al., 1983). The attenuation of the beam from the bone scan is measured and bone mineral density (g/cm²) is expressed as bone mineral content divided by bone width (Wahner et al., 1983). SPA is dependent on the size of the bone and had slightly lower resolution than DPA, DXA and QCT (Glastre et al., 1990). SPA cannot measure bone mineral where there is soft tissue overlay, thus it is limited to measurement of very few sites, for example, the distal radius. SPA is still used frequently for measurement of this site because of its high precision (within 1%) and accuracy, low cost and low radiation.

DPA, a more advanced technique than SPA, involved transmission of two separate photon energies of gamma radiation through bone and soft tissue (Wahner et al., 1983 and 1988). This method can be used at axial skeleton sites such as the lumbar spine and hip, which are primarily trabecular bone. It
measures bone mineral density, in g/cm$^2$, and bone mineral content. Like SPA, low resolution quality, high radiation and scanning time are limiting factors of this technique.

QCT involves a pulsing X-ray which circles around the entire bone so attenuation is measured at many different angles. A cross-sectional view of the bone is derived by a sophisticated computer program and a true volumetric bone density is calculated (g/cm$^3$) (Wahner et al., 1983). Although this method gives a truer representation of bone density because it measures the three dimensions of bone, and it is precise (within 1.1-2.0% error) (Overton and Wheeler, 1992), it is expensive and involves very high dosages of radiation (Glastre et al., 1990). This limits its clinical use, and precludes its use for children and adolescents.

DXA, currently considered the state of the art, evolved from DPA and is more accurate and precise as well as having a lower radiation exposure. Two X-rays of different energy levels are collimated and directed into the body where the attenuation of the X-rays by the chemical components of the body yields three components of body composition (bone mineral, bone mineral free lean and fat tissue) (Sartoris et al., 1996). DXA is capable of measuring bone mineral content, density (g/cm$^2$) and projected area of the axial, appendicular and whole skeleton and has a high-resolution image. Whole body, lumbar spine, proximal femur and the forearm are the most common sites measured. Appendix H shows DXA printouts for the whole body, proximal femur and lumbar spine.

DXA requires less scanning time, 3-8 minutes for the lumbar spine for example, as compared to 20-35 minutes for DPA, which cuts radiation dose and the cost of
measurement. In a performance evaluation DXA was found to have precision error within 2%, over the long and short term using high precision (slower) scan speeds, but the faster scans, standard clinical scan speeds, did not unfavorably alter precision (Mazess et al., 1989; Sievanen et al., 1992). Sievanen et al. (1992) investigated the precision of the Norland XR-26 densitometer and found very similar values for lumbar spine and proximal femur bone mineral density, 1.7% and 1.3%, as reported in the Norland Operators Guide (Norland, 1992). Over the long term (six months) precision error was 0.9% and 1.2% for the lumbar spine and femur, respectively, at the medium speed, and for whole body scans precision was 0.5%.

There was little error introduced if body trunk thickness was between 15-25 cm and if total body fat was below 50% (Kroger et al., 1992; Wahner et al., 1983). This was similar to Mazess et al.'s (1989) finding that there was no significant effect of tissue thicknesses between 10-24 cm on bone mineral or area values for the spine or femur. The bone area estimate correlated 0.97 with the criterion.

The difference between actual and measured area was -3.3 to +3.4% for DXA as compared to -11.6 to +0.7% for DPA (Mazess et al., 1989). Lukaski (1993) reported precision and accuracy scores within 1% for bone mineral density and content using DXA. Comparing DPA and DXA for bone mineral values at the lumbar spine, Wahner et al. (1988) reported better accuracy and precision for the spine phantom and area, and less influence of thickness of patient, measured by DXA, but bone mineral content accuracy was similar for both instruments. Both DXA and DPA have <5mrem entrance radiation exposure but because the scan time of DXA is much less there is a lower total radiation exposure (Lewis et al., 1994; Sartoris et al., 1996; Wahner et al., 1988). In comparison to QCT, DXA correlated highly with indices of bone mineral content and density for the whole
body and forearm and moderately with trabecular bone density (Overton and Wheeler, 1992).

Investigators have concluded that the DXA method has more clinical application because of the above mentioned advantages over SPA, DPA, and QCT (Glastre et al., 1990; Kroger et al., 1992; Wahner et al., 1983). The high precision and accuracy of DXA make it valuable and appropriate for research investigating changes in bone mineral due to some intervention, and because of its low radiation, it is an appropriate instrument for repeat measures, especially for children.

DXA precision and accuracy have also been evaluated on pediatric and adolescent subjects and results have been consistent with those using adult subjects (Chan, 1997), as reported and discussed above. DXA has been used in a number of cross-sectional and longitudinal studies on children and adolescents creating the growing data base for bone mineral values throughout the development years (Faulkner et al., 1993 and 1996; Glastre et al., 1990; Kroger et al., 1993; Lloyd and Eggli, 1992; Plotkin et al., 1996; Zanchetta et al., 1995), as well as numerous studies on elderly subjects, osteoporosis and lifestyle intervention effects on bone mineral.

Research with outcome measures of bone mineral often reports only bone mineral content or bone mineral density, but which one is of more value? Engelke et al. (1995) investigated the effects of variations in bone size, soft tissue composition and positioning on precision of bone mineral density and content values in postmenopausal women using a Norland XR-26 densitometer. The authors concluded that bone mineral density was a better measure to report than
bone mineral content, especially at the femur, since precision was consistently better. Density has been suggested by some as the better measure to report in studies investigating growing children and adolescents with or without interventions, since increases in height with growth will increase content but not necessarily density.

A limitation of DXA is that it only measures two dimensions (width and length) of bone and not the third dimension of bone, depth. Therefore, this areal density expressed in g/cm$^2$ does not represent a true volumetric density. This makes comparison of bone mineral density of bones of different thickness misleading and inaccurate, overestimating density in larger, or more specifically, thicker bones (Hassager et al., 1991). Consider two blocks of bone of the same density, i.e., 1g/cm$^2$ but of different size (figure 1.3). The smaller block has a bone mineral density of 2g/cm$^2$ whereas the larger block has a bone mineral density of 16g/8cm$^2$ which equals 2g/cm$^2$. Thus two bone samples with different projected areas could have the same density yet DXA would calculate a greater density for the larger sized sample (figure 1.3) (Carter et al., 1992).

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<td>Volumetric bone density (g/cm$^3$)</td>
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<td>Projected area (cm$^2$)</td>
<td>2.0</td>
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<td>Volume (cm$^3$)</td>
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<td>BMC (g)</td>
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<td>BMD (g/cm$^2$)</td>
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Figure 1.3  Error in Areal Bone Mineral Density  (Carter et al., 1992)
This size artifact is of particular importance in studying bone density during growth. Faulkner et al. (1995) highlighted this problem by comparing areal bone mineral densities and estimated volumetric bone mineral densities in men and women. Their results demonstrated how measures of areal bone mineral density can be misleading when comparing subjects of different size, i.e., men typically have larger bones than women, since areal bone mineral density was significantly greater at all sites in men than women. However, these gender differences disappeared when volumetric estimates were compared. To address this concern and lessen the error in areal density values due to differing bone sizes, a few researchers have developed estimations of thickness, using standard DXA measurements, so a three-dimensional volume and thus a true density can be determined (Carter et al., 1992; Katzman et al., 1991).

Average thickness of bone was estimated from the projected area and a proportionality constant included to compute a reference volume for lumbar spine (Carter et al., 1992). More specifically, volume was equal to the projected area multiplied by the square root of the projected area. This was then used to calculate a new bone density score; bone mineral apparent density in g/cm³ (BMAD) (Carter et al., 1992). Katzman et al. (1991) computed a corrected density for femoral neck where estimated volume was equal to the projected area multiplied by the projected area divided by the length of the projected area. Estimates of whole body volume have also been developed to compute whole body BMAD (Katzman et al., 1991) using a regression equation of log height and log of whole body projected area but are less valid because the estimated volume is larger.
Carter et al. (1992) also used this idea to better estimate bone strength. Bone strength is determined by bone geometry and material properties and is an important factor in fracture risk, therefore, the ability to evaluate bone geometry is valuable. Bone strength is proportional to the cross-sectional area of a bone but cross-section is not measured by DXA. Using the BMAD score and an approximation of the average cross-sectional area, an index of bone strength was estimated (IBS) for the vertebral spine. These computations may provide a practical alternative to the expensive, high-radiation method of QCT, and a better estimate of true bone density. BMAD has been employed in recent studies of adolescent girls (Dyson et al., 1997; Katzman et al., 1991) but further use of this technique is necessary to confirm its validity.

A similar approach was used by Kroger et al. (1992) who attempted to normalize bone density values for the size of bones in a cross-sectional study of 6-19 year olds in Finland. The authors discovered that the high correlation between age and bone mineral density disappeared when the corrected values were used which suggested that apparent volumetric density did not change significantly during childhood or adolescence. The corrected volumetric density was derived from hypothetical cylindrical shaped models of the spine and femoral neck and the information needed for the formulas was obtained from the DXA scan reports (Kroger et al., 1992). Lateral spine scans, however, may also provide a means of deriving a better estimate of volumetric bone density by combining projections from the more typical anteroposterior spine scan and the lateral scan (Sabin et al., 1995). Results of one study showed, however, that the DXA scan underestimated bone mineral content and volumetric bone mineral density and the authors concluded that there were large systematic errors (Sabin et al., 1995).
It is, however, the poor precision of lateral spine scans (74%) that is responsible for the lack of acceptance of this initially promising technique.

DXA has also been evaluated for its precision in measuring the width and length of the humerus and femur bones in a phantom as well as in ten human subjects (Sievanen et al., 1994). This could have implications for measuring and interpreting changes in bone density and geometry in the growing child. The precision for the width measurements in the humans ranged from 0.4% (humerus and femur midshaft) to 0.9% (proximal humerus) and the precision for length was 3.7% for the femoral neck and 0.3% for the humerus (Sievanen et al., 1994). More recent and novel suggestions for DXA use involved measurement of size parameters for the prediction of structural strength and stiffness indices indicating that DXA may be valuable in applications other than its standard bone densitometry and body composition applications (Sievanen et al., 1995).

Other limitations in using DXA arise when measuring large subjects as body thickness and high body fat content decrease precision, as does the existence of deformity and compression fractures of the spine and soft tissue calcification (Morita et al., 1993). Laskey et al. (1991), using a water and lard model for fat and fat free tissue, found that precision decreased with water (representing soft tissue) depths above 12 cm and concluded that precision would be lowest in obese subjects. These problems, however, would not be an issue when measuring the healthy adolescent subject.

Comparisons of results obtained from different manufacturers' machines is difficult because of variability in results (Morita et al., 1993). Efforts are being made to try to alleviate this problem (Faulkner and McClung, 1995; Genant et al.,
Careful repositioning of subjects for repeat measures, research purposes, data bases and comparison to norms is very important for reproducibility (Engelke et al., 1995; Morita et al., 1993). Manufacturers of densitometers, technician training institutions, and researchers have taken great care to outline the measurement procedures, positioning of subjects, and quality control rules and guidelines to attain high precision and reproducibility over the long term (Faulkner and McClung, 1995; Gluer et al., 1993; Koo et al., 1995; Norland, 1992; Orwoll et al., 1993; Sartoris et al., 1996).

Since DXA is also capable of measuring soft tissue it is being considered as a possible criterion technique for measuring body fat and composition (Chan, 1997). The technique separates out bone mineral, bone mineral free lean, and fat and can therefore, yield a percentage body fat and thus has implications for use in nutritional and physical activity studies interested in changes in body composition. Lukaski (1993) reported reproducibility of 99% for soft tissue composition and Slosman et al. (1992) concluded that DXA measurements of whole body composition were accurate and precise, determined by comparison to whole body potassium-40, in being able to detect changes in body composition in a group of AIDS and cystic fibrosis patients. DXA has been used in a cross-sectional analysis of subjects aged 4-16 years to measure body composition and was compared to scale body weight and skinfolds (Ogle et al., 1995). DXA weight underestimated scale weight by 0.83 kg. Percent body fat measured by DXA correlated well to percent body fat estimated from skinfolds for males, but not as well in females because DXA tended to overestimate percent fat (Ogle et al., 1995).
DXA appears to be the technique of choice for measuring bone mineral in most individuals because of its high precision and accuracy and low radiation. It has been well used in research and is considered appropriate for measuring all ages of subjects either for short term clinical assessment or for longitudinal and intervention research to measure changes in bone mineral. However, its major limitation of only measuring areal density poses problems for use with growing subjects or in comparisons of groups having different bone size. Calculation of BMAD represents an attempt to alleviate this problem, but it is not yet widely used. Researchers suggest caution in interpretation of bone mineral density results and stress the importance of quality control in measurement.

1.5 Factors Affecting Bone Mineral
Researchers have recently put efforts into identifying factors which may affect bone mineral in an attempt to prevent or reverse osteoporosis. Hereditary factors account for a large portion of the variance in bone mass, e.g., 46-62% (Krall et al., 1993) but nearly half of the variance could be attributed to non-hereditary factors (Bailey, 1996). Lifestyle behaviours, such as physical activity, nutritional intake (especially calcium) (Sanborn, 1990), smoking, and caffeine consumption are examples which have small hereditary influences on their explained variance in bone mineral (Fehily et al., 1992; Toss, 1992; Valimaki et al., 1994). Individuals have some control over these variables and could manipulate them in order to optimize bone mineral status throughout life. Since studies on adult and elderly populations have given some indication that these factors are important to the maintenance of bone mineral and to the slowing of bone loss, it makes sense to find the optimal conditions of these lifestyle factors during the growth phase of adolescence to foster attainment of one's genetic peak bone mass (Rico et al., 1994). Few studies have investigated the effects of
these lifestyle factors in the adolescent age group, so most of the recommendations for optimal bone mineral attainment have been derived from studies on adults. The following sections review the possible effects of these lifestyle factors on bone mineral with particular emphasis on research with the adolescent population because of the potential impact that attainment of high peak bone mass during growth could have on osteoporosis prevention.

i) Mechanical Loading and Physical Activity

Mechanical loading through physical activity has been well reviewed and documented as playing a key role in the development and maintenance of bone mass (Bailey et al., 1990; Martin and Bailey, 1993; Chillibeck, 1995; Forwood and Burr, 1993; Geusens and Dequeker, 1991; Martin and Brown, 1989; Snow-Harter and Marcus, 1991). Welten et al. (1994) who were involved with the 15-year Amsterdam Growth and Health Study of individuals aged 13 through 28, concluded that physical activity in males and body weight in females, as opposed to calcium intake, were the only significant predictors of bone mineral density. This result was slightly misleading though since calcium intake tended to be high in that area so may not have been a significant contributing factor (Heaney, 1995) yet the results still emphasized the importance of physical activity. The more recent reviews and research studies have attempted to further clarify the exercise type (loading mode), intensity (frequency and strain of loading) and timing best suited for increases in bone mineral yet no consistent findings have been documented because of the differences in subjects used, interventions and measurement methods (Bassey, 1995; Chesnut, 1993). More research is needed in this area to clarify the optimal loading modes and frequencies (Kannus et al., 1996).
Situations of complete bone unloading, unilateral loading training studies, and animal models of limb loading have provided unequivocal evidence of the importance of mechanical loading for the development and maintenance of bone mass. Activity-recall, cross-sectional studies of various athletic groups, adult exercise intervention studies and the one adolescent exercise intervention study help build the evidence for the importance of physical activity in bone accrual.

**Animal Studies:**

Exercise in animals and loading of animal limbs in controlled laboratory settings has provided a means to isolate the effects of different magnitudes and frequencies of load on bone. The responses in animal bone give some indication as to what may happen in human bone and help clarify the characteristics of the load that produces an optimum osteogenic response. The extensive work of Lanyon et al. (1982) including his more recent work with limb-loading models, as well the development of the mechanostat theory (Frost, 1987), has provided a great deal of insight into this area.

The mechanostat theory argues that a minimum effective strain is needed for bone formation to occur. Bone cells detect any increased strain and form more bone which then reduces the strain response to that particular load. Progressively higher strains are thus required to stimulate continued bone formation (Frost, 1987 and 1993). The theory ensured that species-specific bones would adapt to sustain their characteristic lifetime physical activity levels and patterns. In humans appropriate levels of activity must be maintained throughout childhood and adolescence to benefit from this bone adaptation (Parfitt, 1994). Frost (1987) focused on the importance of strain magnitude to bone formation but other aspects of strain, such as distribution and number of
loading cycles could also be important factors influencing bone adaptation (Skerry, 1997). In a recent article, Lanyon (1996) stated, based on his research of loading animal limbs, that functional strains, i.e. those that produce an osteogenic response, are strains that have uneven distribution, or are novel or different, are of high magnitude and rate. A very dramatic finding was that only a few loading cycles, producing these types of strains are required to saturate the osteogenic response, but loading must be regular (daily or every other day) to maintain any level of bone mass (Lanyon et al., 1984). Lanyon (1996 and 1997) also stated that load bearing could be the most important functional influence on bone mass and architecture.

One of the most significant findings through animal limb-loading research was reported by Lanyon et al. (1984). The researchers fixed turkey ulnas so they only experienced loading induced by the researchers which varied from complete unloading, loading intermittently in compression for 100 seconds per day or loading continuously in compression. The similar loads were applied dynamically and statically. After eight weeks the statically-loaded and non-loaded bone both had increased intracortical porosity and decreased cross-sectional area. The intermittently loaded bones showed a 24% increase in cross-sectional area with new bone being deposited mostly on the periosteal surface. This study clearly shows the beneficial effects of dynamically applied loads as compared to similar loads applied in a static manner. The loads applied were even slightly less than those normally experienced by the turkey during wing flapping.

Chillibeck et al. (1995) and Forwood and Burr (1993) have summarized some of the main findings from animal studies involving exercise and limb loading. A
few examples of this research are provided below to emphasize the contribution of these studies to the understanding and progress in human research of mechanical loading, however, it is not the intent to detail all the research as the focus of this present research is on humans.

Prepubescent rats subjected to moderate exercise, 2 km of treadmill running each day for two weeks, had heavier bones with greater calcium content, and bone volume but not bone density, than the control animals (Forwood and Burr, 1993). Similar results were also reported in pigs (Forwood and Burr, 1993). Wheel and treadmill running, and swimming have been shown to increase bone mineral content, bone weight, and volume (Forwood and Burr, 1993). These studies supported Frost's (1987) mechanostat theory. High-intensity and long-duration activity, though, resulted in rats having lighter and shorter femurs as compared to the responses from moderate exercise, and as observed in the control rats. Both cortical and trabecular bone responded negatively to intense exercise. This result indicated a threshold effect of exercise intensity for positive effects on bone formation (Forwood and Burr, 1993).

Chillibeck et al. (1995) summarized evidence of increased new bone formation on loaded bone surfaces, especially the periosteum, since that is where the muscles attach and thus where the greatest strains are experienced. Animals that have exercised required higher bending loads to actually break the bone, supporting the responses of bone to loading of enhanced bone formation and structural and mechanical properties. Bone formation occurred where bone had been compressed and the strains the greatest and did not form where bone experienced tensile loads and the least strain (Chillibeck et al., 1995). Studies of sheep, investigating strain rates, frequencies and distribution, supported high
strain rates and magnitude, applied over a short duration, providing dynamic, intermittent and varied distribution of strains as being the most osteogenic (Chillibeck et al., 1995). Skerry (1997) also stated that high strain rates, rather than low or moderate ones, were more effective in stimulating bone formation, however, strain magnitude may be of greater importance than the number of loading cycles (Chillibeck et al., 1995).

These animal studies have also shown maintenance of the positive effects of loading on bone in childhood into adulthood and that adult bone responds differently to loads than growing bone (Chillibeck et al., 1995; Forwood and Burr, 1993). For example, adult rats showed no change in cross-sectional moment of inertia, whereas young rats did and also had greater periosteal formation. Parfitt (1994) also stated that bone is able to adapt to mechanical loading much more readily during growth as opposed to after maturity. This suggested a possible greater benefit of mechanical loading on the skeleton during growth and the potential for increased peak bone mass.

Based on the animal research there is evidence for recommending exercise that produces muscle overload, and high loads and impact, a variety of load distribution, in a few intermittent, dynamic cycles on bone during growth (Kannus et al., 1996; Lanyon et al, 1984; Skerry, 1997). Aerobic-type exercise produces dynamic strain and high strain rates but low peak-strain magnitudes. Weight training provides dynamic, high strain loads of varying load distribution but are considered by some to be performed in a more static nature at low rates. Skerry (1997) suggested that if two of the strain criteria are met e.g. magnitude, duration or distribution, but strain rate is low that osteogenic responses could still occur. The animal studies provide insight into the possible responses in
human bone to mechanical loading and there is little evidence to suggest a major
difference between animal and human bone in responses to loading (Skerry,
1997). Nonetheless, human research is needed to clarify the responses in bone
and the optimal osteogenic load characteristics, using the information gained
from animal research (Kannus et al., 1996).

Unloaded Bone:
Unloading of bone causes the most rapid reduction in bone mass, even more so
than that caused by the rapid changes in hormones in the first five years
postmenopause (Martin and Brown, 1989). An extensive review of the
biomechanical responses of bone to weightlessness situations (Zernicke et al.,
1990) indicated that individuals in space flight showed significant bone loss,
increased urinary and fecal calcium loss as well as hydroxyproline suggesting
increased bone resorption. The duration of space flight did not relate
significantly to the amount of bone loss thus suggesting the presence of dietary
and exercise influencing factors. Bone loss may plateau and loss may be
irreversible in this situation. Significant changes were not seen in bone density
of non weight-bearing sites (radius and ulna) but losses of 3-8% in the weight-
bearing calcaneus occurred among participants in four different space flight
missions. This indicated that weight-bearing trabecular bone may be most
sensitive to weightlessness situations (Zernicke et al., 1990). Extensive rat
studies simulating space flight have reported that impaired bone matrix
maturation, changes in bone geometry and strength, especially in vertebral
bodies, and increased susceptibility to fractures occur with weightlessness
(Zernicke et al., 1990). Human patients in bed rest situations, which induced
negative calcium balance, showed a 1-2% loss of bone calcium after six weeks in
a body cast. These estimates of calcium loss often excluded sweat losses and,
therefore, the amount of calcium lost may have been underestimated (Zernicke et al., 1990).

Paraplegia is another example of an unloaded state for the lower limb bones. Goemaere et al. (1994) found significant reductions in the total hip region and in the femoral shaft of paraplegics, by 33% and 25% respectively, as compared to age-matched controls. However, subjects that engaged in regular, daily standing activities with the use of support or brace devices showed a significant preventative effect on the femoral shaft as compared to those paraplegics who did not stand.

**Body Weight:**

Considering that body weight is supported by the skeleton, thus imposing a load on the skeleton, and the fact that daily standing helped maintain bone density in paraplegics (Goemaere et al., 1994) it is obvious that body weight may influence bone density. The relationship between body weight and bone density has been well documented, so much so that it would be rare to find a recent study on bone mineral density that did not control for body weight of the subjects. More recent investigations have also looked at the components of body weight, i.e., lean mass and fat mass, and their relationship to bone density. In a review article by Wardlaw (1996) body weight, lean mass and fat mass were stated as having weak to moderate correlations to bone mineral density. In studies investigating predictors of bone density, body weight is often the strongest or only significant predictor (Miller et al., 1991; Slemenda et al., 1990).

A subset of the Framingham study cohort was used to investigate how weight or body mass index affected bone mass (Felson et al., 1993). The subjects had been
weighed repeatedly over 40 years. The results indicated that weight and body mass index explained between 8.9-19.8% of the variance in bone mineral density, and that weight change was the strongest explanatory factor at all sites in women, but not in men. Reid et al. (1992) also found a strong correlation between total body bone mineral density and weight \((r=0.69\) in women, \(r=0.6\) in men). They further discovered that bone density was related to fat mass but only in women. Aloia et al. (1995) found similar results of a strong relationship between fat mass and total body bone mineral density in postmenopausal women but fat free mass was a stronger determinant in premenopausal women.

In children 1-15 years old body weight had the highest correlation of 0.9 to lumbar spine bone mineral density (Glastre et al., 1990). Similarly, in a study of 299 boys and girls aged 6-18 years, body weight was the single strongest predictor, and when combined with pubertal stage, accounted for 80% of the variation in the lumbar spine bone mineral density (Rubin et al., 1993). In a group of adolescent girls aged 14-18 years, body weight significantly correlated with all bone mineral measures (total body bone mineral content \(r=0.55\), metacarpal thickness \(r=0.63\)) (Rico et al., 1994). Lean body mass was also significantly correlated with total body bone mineral content and density and regional density in the trunk, arms and legs. This finding, however, is not surprising since body weight and lean body mass are very highly correlated. In 5-18 year old normal weight and obese children and adolescents, lean mass was the best correlate of total body bone mineral content (Manzoni et al., 1996). Rico et al. (1994) looked at weight changes across seasons and the effects on total body bone mineral content. In contradiction to the studies mentioned above, these researchers found that weight increased through the winter as total body bone mineral content decreased and, in the summer, body weight decreased.
while total body bone mineral content increased in a group of premenopausal women. This could have implications for research investigating bone mineral changes over short durations and should be considered with other lifestyle factors that could be affecting bone mineral and body weight changes during different seasons, such as diet and exercise patterns.

With the strong relationship between body weight and bone mineral content one may wonder if the heavier weight of an obese individual could contribute to higher bone mineral content and thus be a preventative factor for osteoporosis. A body mass index between 26-28 may offer some protection for bone mass whereas a body mass index of 22-24 may increase risk for low bone mass and osteoporosis (Wardlaw, 1996). However, McCormick et al. (1991), who showed an increased spinal mineralization with increased body weight in 312 normal weight subjects aged 5-19 years, did not observe further increases in spine bone mineral in the 23 obese (above the 95 percentile for normal weight) subjects. Other factors, such as the proportions of lean body mass or fat mass and levels of physical activity may need to be considered to explain this.

A strong relationship between body weight and bone mineral content is clear. When also considering the fact that areal bone density, the outcome measure obtained by DXA, is dependent partially upon size, the necessity for controlling for body weight in studies investigating bone mineral changes over time or in different sized populations becomes even more evident. Failing to control for weight, especially in physical activity intervention studies involving impact loading where the load is partially dependent upon one's body weight, would lead to misleading results and conclusions.
Previous Physical Activity:

Cross-sectional studies of adult and elderly subjects have indicated higher bone mineral densities in those who were more active during their younger years, as determined by activity recall. These studies provide some valuable information. However, controlling for the possible large error in recall questionnaires, especially the longer the recall time, different methods of quantifying physical activity and other possible confounding variables is difficult. In a study of perimenopausal women, only a non-significant dose-response relationship was found between their high-school physical activity levels and bone mineral density, measured by DPA at the lumbar spine and by SPA at the radius (Zhang et al., 1992). A similar study in older women aged 60-91 revealed that low childhood physical activity was significantly related to lower bone density at the femoral neck measured by DPA (Ward et al., 1995). Ulrich et al. (1996) also reported that lifetime weight-bearing exercise was a predictor of bone mineral density in women, mean age 41 years.

Stronger evidence from recall studies was shown in studies of young adult women, possibly because of less recall error. Teegarden et al. (1996) assessed five years of previous physical activity, including leisure, occupational, high school and college sports activity, in a group of women 18-31 years of age. Activity was measured in terms of estimated energy expenditure. Occupational and leisure activity were significant predictors of most bone measures (total body, femoral neck and spine bone mineral content and density) except femoral neck bone mineral density. In addition, high-school physical activity was a significant predictor for total body bone mineral content and density, femoral neck density and spine bone mineral content (Teegarden et al., 1996). Valimaki et al. (1994) observed bone mineral density measures in 20-29 year old males.
and females after evaluating lifestyle behaviors over the previous eleven years. Subjects were part of the cardiovascular risk study in Finnish children and adolescents which began in 1980 when subjects were between the ages of 3 and 18 years. Physical activity was estimated three times over this eleven-year period by the number of sessions of activity exceeding 30 minutes per week. Total exercise correlated positively to femoral neck bone mineral density for all ages after adjusting for body weight. When subjects were categorized based on amount of physical activity, significantly higher femoral neck bone mineral densities were found in women as activity index increased (Valimaki et al., 1994).

Fehily et al. (1992) also conducted a follow-up study in young adults aged 20-23 years who initially were involved in a milk-supplementation study beginning 14 years earlier. Current physical activity and activity levels at age 12 were estimated using a questionnaire asking about the range of sport activities and the number of months per year they participated. A significant positive relationship between activity levels at age 12 and radial bone mineral density (the only site measured in this study) was found for those active more than seven hours per week compared to those active around one hour per week. These studies suggested that physical activity during early adolescence may be important for the attainment of higher bone mineral densities, but the methodological limitations of these recall studies must be remembered when interpreting results.

**Athletes:**

Cross-sectional studies of various young-adult aged athletes have shown higher bone densities in athletes in certain sports as compared to other sports, and as
compared to age-matched non-athletic controls. A study comparing bone
densities of adolescent soccer and swimming athletes found that swimmers had
the lowest calcaneus density in both genders (McCulloch et al., 1992, Orwoll et
al., 1993). A similar study comparing young-adult weight-bearing athletes with
swimmers revealed that gymnasts had higher femoral neck, trochanteric and
whole body densities than non-athletic controls and swimmers, even when
corrected for body mass (Taaffe et al., 1997). Comparison between female
collegiate competitive runners and gymnasts and non-athletic controls showed
that runners had the lowest lumbar spine, femoral neck, and whole body
densities, a result which was maintained when similar menstrual histories of the
athletes were considered (Robinson et al., 1995). Ballet dancers were found to
have 6% higher total body bone mineral density than controls, even considering
their later age of menarche and low body weight which can both have negative
influences on bone density (Lichtenbelt et al., 1995). Female weight lifters had
significantly higher weight-adjusted bone mineral densities in their lumbar
spine, distal femur, patella, proximal tibia and distal radius than endurance
orienteerers, cross-country skiers and cyclists, as well as the control group
(Heinonen, 1993). Women involved in aerobics plus muscle-building exercise
had greater lumbar spine density than the non-exercising controls and those
who solely performed aerobics (Davee, 1990). A cross-sectional investigation of
middle-aged male competitive weight lifters found a 12% and 13% higher
trochanter and lumbar spine bone mineral density, respectively over age
matched controls (Karlsson et al., 1993).

More recently a study of competitive female volleyball players, mean age 20.9
years, revealed higher bone mineral densities at all sites, including hip, spine
and humerus measured by DXA, than non-active controls (Alfredson et al.,
consistent conclusion amongst these comparative studies was that athletes involved in weight-bearing activities generating high impact loads and muscular contractions had the highest bone densities, more so than those athletes involved in endurance sports, indicating that this type of activity could have the most powerful osteogenic stimulus. Confounding variables, however, such as age, years of past training, current training regimens, menstrual and nutritional status, and measurement methods only allow for associations, at best, to be determined.

A question recently raised, naturally, was whether these athletes retained the benefit of their higher bone density after retiring from their competitive sport. A review article by Suominen (1993) revealed, as the studies reviewed above did, that athletes tended to have higher bone density than non-active individuals and that continuation of life-long training and exercise, even at lower frequencies and duration, helped maintain higher levels of bone density. Karlsson et al. (1995) who had previously observed bone density in weight lifters (Karlsson et al., 1993) found that male ex-weight lifters, 50-64 years of age, who had quit their competitive sport at least 30 years previously, had total body and spine bone densities still higher than controls. However, only a non-significant difference existed at the femoral neck and differences at all sites disappeared after age 65 years. This may indicate that, independent of later-life physical activity, the benefits of earlier gain may not be maintained.

Unilateral Loading:
Substantiating the conclusion that weight-bearing and higher impact loads are more beneficial to bone was the fact that athletes in sports requiring unilateral loading showed higher densities in their playing extremity. Young adult, female
competitive squash players had higher bone mineral density and content in the proximal humerus and ulnar shaft of their playing arm than their non-playing arm (Haapasalo et al., 1994). A number of similar studies have compared dominant and non-dominant arms of tennis players and found that effects of loading are site-specific and the unilateral loading nature of the sport was associated with greater bone mineral densities in the playing arm compared to the contralateral arm (Huddleston et al., 1980; Martin et al., 1987; Vuori et al., 1994). Martin et al. (1987) found that adults, mean age 60 years, who had played tennis at least three times per week for 25 years had greater muscle area, cross-sectional area of the radial and ulnar cortex and medullary canal, greater hand and wrist breadths and greater bone mineral content of the humerus and radius in the dominant arm. A high correlation was found between the forearm cortical bone area and muscle cross-section but cortical bone density was not significantly different which suggested size changes due to the loads as opposed to compositional changes (Martin et al., 1987).

Bones with a larger cross-sectional area are stronger and capable of withstanding greater loads, and thus are more effective in resisting fractures. Bone strength is a complicated function of bone size and architecture. Few studies, however, have focused on whether increased physical activity could increase bone dimensions beyond those expected in normal growth. The study investigating the differences between non-dominant and dominant forearms of tennis players showed increases in bone size, but not density (Martin et al., 1987) indicating the potential for exercise to stimulate increases in bone size. If bone size could be increased it would be another preventative element against osteoporotic fractures (see section 1.6 for more on bone size and skeletal area).
A unique study, attempting to eliminate some of the possible variances in results of typical exercise training studies, cross-sectional observation and comparison studies, involved a one-year unilateral leg strength-training program for young women (age 19-27 years) where their other leg served as the control (Vuori et al., 1994). The left leg was trained using a leg press at 80% of one repetition maximum, five sets of ten repetitions, five times per week for 12 months and the right leg served as the control. Bone mineral density and content increased non-significantly in the trained limb and an insignificant increase was also noted in the untrained limb. Compared to a control group the changes were also insignificant. Heinonen et al. (1996) continued this study and trained the upper left arm at the same intensities as described in Vuori et al. (1994) and followed up with an eight-month detraining period. Again, the differences between the trained and untrained limb bone mineral density were insignificant despite significant strength gains, but changes were slightly greater in the trained limb. After eight months of detraining the trends remained the same.

To summarize, these unilateral loading studies indicated that there was little positive effect on bone mineral density yet some positive effect on bone size. The study's design implies that subjects acted as their own controls but there was no true control groups which is a major weakness of these studies.

**Weight-Bearing Activity:**

Some physical activity intervention studies have also revealed the superior effects of weight-bearing and high impact load activities on bone. However, an eight-month study of young adult women involved in progressive running or weight lifting showed similar increases in lumbar bone mineral for both groups and no change in the proximal femur (Snow-Harter et al., 1992).
intervention period may have been too short or the exercise stimuli were too similar in load to elicit different osteogenic responses. The weight-training program involved working at an intensity of 65-75% (of one repetition maximum) in the first three months and up to 85% in the last two months of training, completing 8-12 repetitions of each of the 14 exercises in the circuit. The running program involved at least three runs per week and progressed from 4.2 ± 2.3 miles up to 10.4 ± 4.9 miles per week. A similar study of greater duration revealed significant increases in spinal, femoral neck, trochanter and calcaneal bone mineral density in the aerobics plus weight-training group as compared to the stretching group over a two-year intervention (Friedlander et al., 1995). The weight training in this study, however, involved the use of free weights, dumbbells and barbells as opposed to the Nautilus equipment used by Snow-Harter et al. (1992). A study involving women aged 36-67 years participating in an endurance and home weight-training program for one year found no increases in bone mineral content or density (Peterson et al., 1991). However, the training program involved only six upper-body exercises using wrist weights and a barbell, completing 8-12 repetitions, three times per week and progressively increasing weight as subjects were able. In another investigation though, just the addition of intermittent bouts of skipping and jumping into an exercise class and daily jumping (50 repetitions) at home resulted in a significant increase of 3.4% in trochanter bone density in young women over a six-month period compared to those who just participated in an exercise class with no high-intensity bouts and daily walking or swimming (Bassey and Ramsdale, 1994). The authors continued the study for another six months by crossing over the control subjects to the exercise program with the high impact bouts and also found this group to increase by 4.1% in trochanter bone density. Methodological differences, such as in the bone sites measured
and the technology used (SPA, DPA, DXA, QCT), exercise-intervention modes and intensities, and duration of training, between these studies made it difficult to reach conclusions about threshold intensity or duration of exercise needed to elicit significant positive results on bone, or about different effects at specific bone sites due to variations in loading.

The greater potential for positive effects on bone through high impact activities has led researchers to focus specifically on the effects of weight-training. An 18-month study of resistance training at an intensity of 75-80% one repetition maximum, 8-12 repetitions, in women aged 28-39 with a high calcium intake (mean >1000 mg/d) showed significant increases in lumbar spine and trochanter bone mineral density from baseline measures over the control group (Lohman et al., 1995). No changes were found in total body, leg or arm densities. A one-year study investigating the effects of two different intensities of resistance training (40% and 80% one repetition maximum) on bone in elderly women (mean age 68.3 years) found no significant between-group bone mineral density changes (Pruitt et al., 1995). A study involving use of Nautilus equipment with subjects completing 2 sets of 20 repetitions at 60% one repetition maximum was not sufficient to cause significant change in calcaneus or the lumbar spine bone mineral density, however, a slight increase (0.81%) was noted in the lumbar spine of the training group while the control group exhibited a decrease (0.5%) (Gleeson et al., 1990). Also, paired t-tests between matched pairs showed significant differences in percentage change at the lumbar spine. A study on elderly women (50-70 years) who completed a one-year intense weight-training program of three sets of 8-12 repetitions at 75-80% one repetition maximum 2-3 times per week found a mean increase or maintenance of bone density in the lumbar spine, femoral neck, and total body (Nelson et al., 1994).
Further inconsistencies regarding the effects of weight training were shown through a nine-month weight-training study which resulted in decreased vertebral bone mineral density in premenopausal women (mean age 36.2 years) (Rockwell et al., 1990). This study involved training on an eight-station Cybex machine circuit with subjects completing 1-2 sets of 12 repetitions working at 70% of one repetition maximum, two times per week for nine months. Thirteen of the original 15 subjects completed more than 4.5 months of training, but those completing this short time of training were still within the bone remodeling transient period which may have been the reason for the results showing a decrease in bone mineral density.

The training intervention programs used in research studies have resulted in different effects at each bone site yet there are few consistencies in site-specific results amongst similar studies. This demonstrates that the effects of loading may be site-specific as well as load-dependent. Kerr et al. (1996) specifically looked at this issue in their study involving a one-year progressive resistance-training program in postmenopausal women aged 40-70 years. The women were not previously active more than three hours per week and were divided into either a high-load, low-repetition (three sets of eight repetitions) or a low-load, high-repetition (three sets of 20 repetitions) training program using both free weights and machine weights. They trained one leg and one arm only while the opposite limbs acted as non-exercising control. The results showed significantly greater increases in trochanter, Ward's triangle and distal radius bone mineral density in the high-load, low-repetition group than those in the non-exercising control limbs. The authors concluded that the training positively affected three of the four hip sites and one of the three forearm sites which is
consistent with many other training studies. This result further supports the hypothesis that different bone sites respond differently to loading and that magnitude of load is more important than the number of loading cycles (Kerr et al., 1996). However, the lack of control for total work may also be a confounding variable affecting the differences observed between groups. The lumbar site which is commonly reported in other studies was not measured in this study, and the subjects were of postmenopausal age, therefore, application of results to the young adult or adolescent population is limited.

Muscular Strength and Bone Mineral:
Increase in muscle strength has been a consistent result in most of the training intervention studies, whether an increase in bone density resulted or not. The relationship between muscle strength and bone density has been investigated by many researchers as well as the notion of site-specificity of such a relationship. For example, grip strength was a determining factor in the dominant arm radial bone mineral density of young college athletes (Tsuji et al., 1995). In another study of healthy, non-athletic women aged 20-30, trunk extension and flexion correlated significantly to spine bone mineral density, and knee flexion and extension correlated significantly to femoral neck bone mineral density (Eickhoff et al., 1993). Snow-Harter et al. (1990) also concluded that muscle strength was a significant independent predictor of bone mineral density in women, aged 18-31 years, and accounted for 15-20% of the variance in density. Specifically, femoral neck density correlated significantly with back strength and biceps, back and hip adductor strength correlated significantly with hip bone mineral density. Similarly in men of the same age with low or moderate levels of physical activity, muscle strength was a significant predictor of bone mineral density of the total body and femoral neck (Nordstrom et al., 1997).
Nordstrom et al. (1996) also looked at this issue with adolescent boys of different activity levels. The highly-active group had been training for at least four years and trained at least four hours per week and up to ten hours per week as hockey players which also included weight training and aerobic training both in and off season. The low-active reference group were active less than three hours per week. Quadriceps and hamstring strength and bone density of the total body, tibial tuberosity and proximal tibia were measured. Quadriceps strength was higher in the highly-active group as opposed to the reference group, but was a significant predictor of tibial tuberosity density for the reference group but not for the highly-active group. Bone mineral density at this site was significantly higher in the highly active group but no significant differences were noted at the proximal tibia site. The authors concluded that the higher density observed at the tuberosity site of the highly-active group was due to the forceful-type contractions producing great strength increases as the weight-bearing load involved in hockey is considerably less than other weight-bearing sports (Nordstrom et al., 1996). The positive association between muscle strength and bone density was observed only up to a certain level of strength (20% increase), above which no further benefits were gained. The results of this study are valuable for the present work in that it is applicable to the adolescent population. However, the study only involved males and a bone site which is not commonly used as an outcome measure so comparison to other studies is limited at this point.

One other study in pre- and postmenopausal women, aged 21-78 years, however, also measured the proximal tibia and demonstrated a site-specific relationship between strength and bone density (Madsen et al., 1993). These authors demonstrated that quadriceps strength was also significantly correlated
to the proximal tibia but not to the distal forearm. A measure of muscle strength in the forearm may have been a better choice to determine a relationship between distal forearm bone mineral density. These studies certainly suggested that a strong relationship between muscle strength and some bone sites exists and thus exercise to stimulate increases in strength, such as weight-training, may prove to have beneficial effects on bone density as well. However, it must be kept in mind that the relationships may not be causal since they are derived from cross-sectional studies.

Even with similar modes of training, i.e., weight training, the differences in the actual training protocols, age of subjects and the possible differences in bone metabolism at the different ages, again made it difficult to draw conclusions regarding the best stimulus for bone acquisition. Trends, associations and some consistencies in results of adult studies could be used to make suggestions for adolescents. For example, it appeared that activity which increased muscular strength, and/or added high intensity loads on the bone was more frequently associated with higher bone density or greater gains in bone mineral than aerobic-only or non-weight bearing activities. The fact that few studies have actually been completed on adolescents, however, precludes description of the optimal physical activity for bone accrual during this time of rapid growth and hormonal changes.

**Studies of Adolescents:**

Recall studies and observational studies with adolescent subjects have shown positive effects of physical activity on bone mineral. For example, Welten et al. (1994) measured 98 females, six times between ages 13 and 28 on lifestyle parameters and investigated the relationships of those parameters and bone
mineral density at age 28. They found weight-bearing activity was the best contributor, along with body weight, of peak lumbar spine bone mineral density. In another study, adolescents aged 10-16 years were divided into two groups based on information gathered from completed activity questionnaires. Those competing in the impact-load activities, which produced loads at least three times their body weight, such as running, gymnastics and dance, for a minimum of three hours per week plus competitions, had significantly higher femoral neck bone mineral density and a tendency for higher lumbar bone mineral density than those who were involved in activities where the load was mostly produced by muscular contractions, such as swimming (Grimston et al., 1993). However, when the males and females were separated the females in the impact-load group demonstrated no significant differences in bone mineral density at the spine or femoral neck compared to the swimmers. These subjects were matched for race, puberty and body weight but the small number of subjects in each group, eight or nine, resulted in a lack of statistical power.

Bailey et al. (1996) have completed an extensive review of the published studies, categorized by experimental design, on the effects of physical activity on bone. Table 1.1 below was adapted from Bailey et al. (1996) summarizing just the prospective, controlled and intervention studies with adolescent subjects, with more recent intervention studies, completed since publication, added.

A very recent study by Boot et al. (1997) evaluated total body, lumbar spine bone mineral density and volumetric bone mineral density in 205 boys and 295 girls, aged 4-20 years in the Netherlands. Bone mineral density and volumetric bone mineral density increased with age and was higher during puberty. Tanner stage was significantly associated with all bone mineral density variables in girls.
<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects (age)</th>
<th>Measures</th>
<th>Activity</th>
<th>Summary of Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kroger et al., 1993</td>
<td>65 (7-20y)</td>
<td>DXA - BMD/ BMC: FN, LS</td>
<td>little or no PA; 3/hr week athletes 5hrs/wk</td>
<td>no r btwn PA &amp; any bone site; - change in FN, LS</td>
</tr>
<tr>
<td></td>
<td>37F, 28M</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Nicholes et al., 1994</td>
<td>22F</td>
<td>DXA - BMD: PF, LS, TB</td>
<td>5 mo. gymnastics program</td>
<td>gymnast initial BMD; - after 5 mo. LS +2.1%; - TB, PF no change</td>
</tr>
<tr>
<td></td>
<td>11 gymnasts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11 controls</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Rice et al., 1993</td>
<td>35F (14-18y)</td>
<td>DPA - BMD: LS, TB</td>
<td>26 wk hydragym wt. training, 3x/wk, 4 sets, 13 exercises</td>
<td>- no sig. diff. in BMD btwn groups, sig. strength increase in training group</td>
</tr>
<tr>
<td></td>
<td>17 wt-trained</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18 controls</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Slemenda et al., 1994</td>
<td>45 (6-14y)</td>
<td>SPA - BMD: radius, DPA - BMD: PF, LS</td>
<td>normally active questionnaire</td>
<td>PA was sig. predictor of prepubertal BMD at all sites, M &amp; F; no change LS, PF increased</td>
</tr>
<tr>
<td></td>
<td>32F, 13M</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Faulkner et al., 1993</td>
<td>234 (8-16y)</td>
<td>DXA - BMD: TB, arms, legs</td>
<td>normal childhood activity range</td>
<td>BMD dominant arm; non-dominant all ages, M &amp; F; no dif. in legs</td>
</tr>
<tr>
<td></td>
<td>124F, 110M</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Blimkie et al., 1996</td>
<td>36F (14-18y)</td>
<td>DPA - BMC/ BMD: TB, LS BMAD</td>
<td>26 wks, 3x/wk, 4 sets 10-12 reps, 13 exercises on Hydra-Fitness</td>
<td>- sig. increase strength in trained</td>
</tr>
<tr>
<td></td>
<td>16 training</td>
<td></td>
<td></td>
<td>- no sig. dif. in training group in TB or LS; both groups increased in LS</td>
</tr>
<tr>
<td></td>
<td>16 control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boot et al., 1997</td>
<td>500 (4-20y)</td>
<td>DXA - BMD: LS, TB, BMAD</td>
<td>habitual physical activity questionnaire</td>
<td>PA sig. higher in boys,</td>
</tr>
<tr>
<td></td>
<td>205M, 295 F</td>
<td></td>
<td></td>
<td>- no assoc. of PA with BMD, BMAD in girls,</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- sig. + cor. of PA with TB, LS BMD in boys</td>
</tr>
<tr>
<td>Morris et al., 1997 in press</td>
<td>71F (9-10y)</td>
<td>DXA - BMD/ BMC: TB, PF, FN, LS; BMAD</td>
<td>10 mo. high impact strength building exercise, 3x/wk, 30 min.</td>
<td>BMD &amp; BMC sig. &gt; in exercise group for TB, LS, FN, PF &amp; BMD for leg, arm, pelvic, &amp; LS BMAD</td>
</tr>
<tr>
<td></td>
<td>premenarcheal</td>
<td></td>
<td></td>
<td>- FN area sig. increase in trained group</td>
</tr>
<tr>
<td></td>
<td>38 training</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>33 controls</td>
<td></td>
<td></td>
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</tbody>
</table>

Table 1.1 Summary of Studies: Effects of Physical Activity on Adolescent Bone Mineral

*FN=femoral neck  *TB=total body  *BMD=bone mineral density
*LS=lumbar spine  *PF=proximal femur  *BMC=bone mineral content
*PA=physical activity  *sig.=significantly  *M=male, F=female
and was the major independent determinant of bone mineral density; for boys body weight was the major determinant. Physical activity was significantly higher in boys and had a significant positive correlation with lumbar spine bone mineral density in boys but not in girls.

Only one published study has involved a weight-training intervention with adolescent girls (Blimkie et al., 1996). Postmenarcheal girls, matched for age, body weight and level of physical activity were randomly assigned to an exercise or control group. After 26 weeks of four sets of 13 exercises of progressive-resistance training on Hydra-Fitness equipment, no significant increases in the two dependent measures, total body and lumbar spine bone mineral density and content were noted, despite significant strength gains. The authors noted a trend for greater increases in lumbar spine bone mineral density and content, areal bone mineral density, and bone mineral apparent density in the first 13 weeks in the training group over the control group. The study controlled for calcium intake; there were no significant differences between the two groups based on two three-day food diaries and the intakes met the Canadian recommended nutrient intake (RNI) of 700 mg per day (for 16-18 year olds) but not the American recommended dietary allowance (RDA) of 1200 mg per day. The authors suggested that the intake may not have been enough to support growth-related and training-related bone mineralization. The duration of the study may not have been long enough to see an effect of exercise considering the approximate time of the bone remodeling transient (six months) and the results at 13 weeks may be explained by the effects of the remodeling transient.
Two studies have recently looked at the effects of physical activity in premenarcheal girls and have both shown positive results (Dyson et al., 1997; Morris et al., 1997). Morris et al. (1997) carried out a ten-month intervention study with 9-10 year old girls involved in a high-impact strength-building exercise program including step aerobics, dance, weight training and soccer, carried out in a school setting. Bone mineral density and content, bone area and bone mineral apparent density were reported for total body, femoral neck, proximal femur, and lumbar spine. Calcium intake, other physical activity, and sexual maturity were monitored. At the end of the study the exercise group showed significantly greater changes in whole body bone mineral density and content, lumbar spine density, femoral neck mineral content, and proximal femur density, than the control group, after controlling for height and body mass changes. Femoral neck bone area also increased significantly in the exercisers and femoral neck bone mineral apparent density was also greater in the exercisers but did not reach significance. The authors concluded that regardless of the large proportion of observed bone changes associated with growth, bone accrual may be enhanced during pre-adolescence by the high mechanical loading of the exercise program (Morris et al., 1997).

Dyson et al. (1997) compared bone mineral density of 16 gymnasts and 16 non-athletic controls aged 7-11 years. Current calcium intake, physical activity, and sexual maturity status were considered. Bone mineral density and content were evaluated by DXA for whole body, femoral neck, trochanter, and lumbar spine. Bone mineral apparent density was also calculated and QCT scans of the distal radius were taken. The gymnasts had significantly greater bone mineral density at the trochanter, femoral neck and distal radius, and significantly greater bone mineral apparent density for whole body, lumbar spine and femoral neck.
However, there were no significant differences between groups in radial cross-sectional area indicating no association between high-impact loading and bone hypertrophy. The authors concluded that high-impact loading during preadolescence resulted in qualitative changes in bone.

Also, results from the study by Haapasalo et al. (1994) and Kannus et al. (1995) on racquet-sport athletes showed greater positive effects in the active arm bone mineral density if training had begun before menarche. This indicated that enhancement of bone mineral density through physical activity may have its greatest potential during the rapid growth phase of late childhood and possibly into early adolescence. However, the one intervention study in adolescents failed to show significant changes in bone mineral (Blimkie et al., 1996). Despite accounting for volumetric bone density it still may not be possible to see effects of intervention because of being overshadowed by growth changes and the effects of a rapidly changing hormonal milieu.

Two review articles on strength training indicated other positive effects on adolescent health, besides bone health, such as increased strength, sport performance, motor fitness, and possible body composition benefits (Blimkie, 1993; Holloway and Baechle, 1990). Also, there is increasing evidence for a positive relationship between weight training, or exercise in general, and improved self concept and self esteem in adolescents and children (CFLRI, 1994).

Adolescents and Physical Activity:
The general agreement that physical activity is important for adolescent bone development was reinforced in the 1994 Consensus Statement on Physical Activity Guidelines for Adolescents (Sallis and Patrick, 1995). The purpose of
the consensus meeting was to encourage appropriate activity interventions for this age group. The first guideline indicated that adolescents should be active everyday or nearly everyday in a variety of enjoyable, weight-bearing activities, expending energy and by incorporating activity into their lifestyle. The rationale for this was that activity is critical for bone development, reduced risk of obesity and other positive health benefits (Sallis and Patrick, 1995).

Teenage girls are one of the least active age groups according to the Canada Fitness Survey (Stephens and Craig, 1990). Males at any age are generally more likely than females to be active (Sallis et al., 1996; Stephens and Craig, 1990) and a decline in activity is noted with increasing age, especially in the 15-19 year age group. Statistics from the 1988 survey showed this age group to be one of only two to show a decline in activity levels from 1981. Fewer than 15% of girls aged 10-14 years and fewer than 10% of girls aged 15-19 years get regular aerobic activity for 30 minutes per day, three times per week (Stephens and Craig, 1990; Health and Welfare Canada, 1993). A study in females, indicated that physical fitness, measured by maximum oxygen uptake (max VO2), significantly correlated with femoral neck and lumbar spine bone mineral density. Although this study was on subjects aged 20-75 years, it suggested the importance of habitual physical activity for increasing max VO2 and bone mineral density (Pocock et al., 1986). However, max VO2 measured during adolescence is not always indicative of physical activity levels because it increases naturally with growth. School physical education currently receives less time per week than it used to and less time than other academic subjects, is taken for only part of the school year, and is becoming optional in the senior secondary years, despite the efforts of the Canadian initiative to increase physical activity in the schools through the Quality Daily Physical Education Program (Strang, 1995).
Currently, this situation does not allow the potential for physical activity to be an optimal prevention strategy against osteoporosis unless multifaceted community efforts are made for increasing levels of physical activity in adolescent girls (Lawrence, 1996; Sallis and Patrick, 1995; Sanborn, 1990; Strang, 1995).

Further intervention studies on the effects of specific physical activity regimes on adolescent bone mineral are needed based on the conclusions, summarized below, from the adult and few adolescent studies completed to date:

i) physical activity plays a key role in development and maintenance of bone mineral,

ii) unloading of bone results in serious decline of bone mass,

iii) weight-bearing athletes consistently show higher bone densities,

iv) there are mixed results in bone mineral changes, at various bone sites, for similar and dissimilar exercise regimes and ages,

v) weight-trained athletes and the addition of weight training to aerobic exercise regimes positively affects bone mineral density, for most subject groups,

vi) there is some evidence of a positive relationship between muscle strength and bone mineral density,

vii) activity guidelines for adolescents are based on adult studies,

viii) the adolescent growth phase may be the time of greatest potential for bone enhancement,

ix) no long-term physical activity intervention studies have been completed on adolescent females,

x) there may be other potential health benefits gained from physical activity,
xi) adolescent females are generally not very active.

ii) Nutritional Issues; Calcium and Calcium Supplementation
Adequate calcium to ensure the development of an individual's maximal bone mass has been described as possibly being the most promising nutritional approach in decreasing osteoporotic fracture risk (Andon et al., 1994). Calcium has been well documented as important in slowing bone loss in the elderly (Elders et al., 1994; Reid et al., 1993 and 1995; Riggs et al., 1987; Riis et al., 1987) who have reduced absorption efficiency and a tendency towards lower calcium intakes (Heaney, 1993), and in promoting bone maintenance in adulthood (Cumming, 1990; Dawson-Hughes, 1991; Holbrook and Barrett-Connor, 1995; Picard, 1988; Ramsdale et al., 1994; Welten et al., 1995). Heaney (1993) summarized the positive evidence for calcium's effect on bone by indicating that when studies controlled for calcium intake and excluded the first five years postmenopause, 12 out of 12 studies showed a significant calcium benefit (table 1.2). However, not all researchers are as convinced about the benefits of calcium on bone (Kanis and Passmore, 1989) as misinterpretations and inconsistencies of data, and methodological difficulties, such as small subject numbers, low compliance to calcium supplementation, and inaccuracies of reported dietary intake, may confound study results. There have been few controlled studies investigating if calcium increases bone mineral independent of energy intake. Research which may have shown small positive effects of calcium have also shown that other factors, such as physical activity, may be more important for increasing bone mass (Kanis and Passmore, 1989; Welten et al., 1994). One key example of data misinterpretation is the well-cited study by Matkovic et al. (1979) who stated that people living in a community with higher calcium intake had fewer femoral fractures than the community with lower intakes of calcium.
However, lower reported energy intakes (for females in the low calcium intake community), but similar body weights may indicate lower activity levels in this community. Also, childhood calcium intake could have been the key factor in adult bone differences since the differences were apparent before age 30. Physical activity is a key factor affecting skeletal mass (Kanis and Passmore, 1989).

<table>
<thead>
<tr>
<th>Distribution of Positive Studies, by Investigational Design Features</th>
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<tbody>
<tr>
<td>Control of Calcium Intake</td>
</tr>
<tr>
<td>Exclusion of first 5 years postmenopausal</td>
</tr>
<tr>
<td>Control of Calcium Intake</td>
</tr>
<tr>
<td>No</td>
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<tr>
<td>Yes</td>
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<tr>
<td>Total</td>
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<tr>
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<tr>
<td>0/8</td>
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<td>4/7</td>
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<td>Yes</td>
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<td>11/16</td>
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<td>Total</td>
</tr>
<tr>
<td>11/24</td>
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<tr>
<td>16/19</td>
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<td>27/43</td>
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</tbody>
</table>

Table 1.2 Summary of Studies: Effects of Calcium by Investigational Design Features (Heaney, 1993)

Despite methodological problems, the above summary is quite convincing of calcium's effectiveness in adults. Cumming (1990) completed a meta-analysis including 37 published papers, between 1966 and 1989, representing 49 different studies of calcium and bone mass in pre- or postmenopausal women. The study designs included intervention, cross-sectional and longitudinal observation. The results were consistent with Heaney (1993) indicating that supplementation with calcium consistently had a preventive effect on bone loss, an effect more pronounced when baseline calcium intake was low. Cross-sectional studies indicated a small positive correlation between calcium intake and bone mass especially in premenopausal women. Cumming (1990) cautioned about interpretation of results because of methodological inadequacies and differences in author views about what constituted an important calcium effect. Matkovic et
al. (1979) suggested a possible key role of calcium during growth for enhanced bone formation through his study comparing fracture rates in two regions of Yugoslavia, one region characterized by low calcium intakes and the other with high calcium intakes. He concluded that fracture rates were higher in the low intake region and that differences in bone were already present by age thirty. He offered the explanation that the differences in bone occurred during the time of bone growth and that additional calcium could possibly have enhanced bone accretion (Matkovic et al., 1979). Although the study has been criticized (Kanis and Passmore, 1989) its message encouraged further investigation into this area. More recently, with the positive evidence of the effects of calcium in adults, there has been increased recognition of and research focus on calcium's importance during childhood and adolescence for bone accretion (Bonjour et al., 1997; Caufield and Flynn, 1995; Picard et al., 1988). Controversy remains, however, as to its bone-promoting effects through adolescence, especially in conjunction with other lifestyle variables such as exercise (Anderson et al., 1993; Henderson et al., 1995; Martin and Houston, 1987; McCulloch et al., 1990; Prince, 1993; Toss, 1992).

**Calcium Intake of Adolescents:**
Calcium is an essential nutrient and 99% of the body's calcium stores are in the skeleton. Dairy products, dark leafy green vegetables, some nuts, and types of fish which contain the bones e.g., sardines, are foods where calcium is mostly found. The most recent Canadian recommended nutrient intake (RNI) for adolescent girls (aged 13-15 years) is 1000 mg/d (Health and Welfare Canada, 1990) and the U. S. recommended dietary allowance (RDA) is 1200 mg calcium/d for girls aged 11-18 years (Hamilton et al., 1991). The recent consensus statement on optimal calcium intake from the National Institute of
Health (NIH), 1994, suggested that the RDA be increased to 1200-1500 mg/d for adolescents and young adults (table 1.3).

<table>
<thead>
<tr>
<th>age range (y)</th>
<th>mg/d</th>
</tr>
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<tbody>
<tr>
<td>Canadian recommended nutrient intake</td>
<td></td>
</tr>
<tr>
<td>10-12</td>
<td>1100</td>
</tr>
<tr>
<td>13-15</td>
<td>1000</td>
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<td>16-18</td>
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<td>1200</td>
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<tr>
<td>15-18</td>
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<tr>
<td>NIH optimal calcium requirement</td>
<td></td>
</tr>
<tr>
<td>11-24</td>
<td>1200-1500</td>
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</table>

Table 1.3  Summary of Calcium Intake Recommendations

Most teenage girls do not meet the RNI which may negatively affect their achievement of peak bone mass. For example, in a recent survey of high-school students in the Vancouver area 64.8% and 75% did not meet the RNI or RDA, respectively, for calcium (Barr, 1994). Chan (1991) found that only 15% of girls over 11 years old in Salt Lake City, Utah, met the RDA of 1200 mg/d. Whiting et al. (1995) found that more than 25% of girls 13-15 years old in Saskatoon were below the RNI for calcium and the required number of servings of milk products and of fruits and vegetables. This painted a rather poor picture of calcium intake for adolescents but the information can be misleading because, theoretically, RDAs and RNIs are set at values of the minimal required amount of the nutrient for 98% of the population (Schaafsma, 1992). However, considering the normal distribution curve, the majority of the population can meet their minimal requirement at a much lower intake (Schaafsma, 1992). But the definition of "requirement" is unclear, for example, it could refer to the amount needed for just normal growth in height and not necessarily the amount required for attaining maximal peak bone mass (Schaafsma, 1992). The suggestion from the NIH to increase the RDA may be more reflective of the "requirement" considering both growth in height and attainment of maximal
peak bone mass. Poor eating habits, dieting (Perry-Hunnicutt and Newman, 1993), beliefs that dairy foods are only high fat, intolerance to milk products and the over consumption of soft drinks (Frederick and Hawkins, 1992; Mazariegos-Ramos et al., 1995) have been suggested as the reasons why dairy intake is minimal (Barr, 1994; Duerksen, 1996; Guenther, 1986) yet no strong correlations exist between these factors and low dairy intake (Barr, 1994).

**Calcium and Bone Accretion:**

Using data from the Saskatchewan Growth Study, the rate of calcium retention was estimated from annual measures of total body bone mineral content, measured by DXA, and was compared to the subject's actual reported calcium intake (Martin et al., 1997). The assumptions that bone mineral is 32% calcium and that calcium retention rate is on average about 20.3% (Weaver et al., 1995) were made to make this estimation. Case studies of girls with reported high (1589 mg/d), medium (1039 mg/d) and low (576 mg/d) calcium intakes all appeared to have a deficit of intake as compared to their actual bone mineral content gain. This may have indicated that adolescents were truly not getting enough calcium and could have ingested more to further increase bone mass, and/or that absorption and retention rates were actually greater during adolescence, and/or calcium content of adolescent bone was less than 32% (Martin et al., 1997). There is also the possibility that calcium-containing foods were under-reported, a common inherent source of error in self-reported diet records of adolescents (Barrett-Connor, 1991; Livingstone et al., 1992; Rockett and Colditz, 1997; Schoeller, 1990). Another recent study by Weaver et al. (1996) used biochemical markers to predict calcium balance and found that adolescents (age 13.1 years) actually had 4.5 times greater retention than adults (age 22.2 y) and significantly more bone formation and resorption than adults. Andon et al.
(1994) indicated that the absorption factor in adolescents was 40% and that bone accretion was as high as 400-500 mg/d which equated to a necessary calcium intake of 1200 mg/d. However, this value ignored obligatory calcium losses and assumed all calcium retention was in bone tissue. Thus, an absorption factor of 30% and concomitant RDA of 1600 mg/d was suggested as being more appropriate (Andon et al., 1994). This absorption factor was closer to the average of 30% found in an analysis of 112 calcium balance studies in adolescents by Matkovic et al. (1992).

Matkovic et al. (1990) have also completed two-week calcium balance studies on 28 adolescent females followed by a two-year intervention of calcium supplementation. There was a nonsignificant greater increase in bone mass seen over time in the calcium-supplemented group (1640 mg/d) than in the control group (750 mg/d).

The efficiency of calcium absorption seems to be greater when the body's need for it is greater, e.g., during the adolescent growth spurt (Matkovic, 1991; Weaver, 1994). Abrams and Stuff (1994) evaluated the differences in calcium absorption, by dual-tracer stable-isotopes, between prepubertal, early pubertal and late pubertal girls (n=51) and found that the early pubertal period was associated with the highest calcium absorption efficiency (34.4%) as compared to 25.9% in late puberty and 27.7% in prepuberty. The calculated calcium retention was again highest for the early pubertal girls (161 mg/d) as compared to the late pubertal (44 mg/d) and prepuberty (131 mg/d) girls. Calcium intake for all three groups ranged from 907 mg/d (prepuberty) to 955 mg/d (late puberty). They concluded that the peak periods for calcium retention and absorption were during prepuberty and early puberty, and that increased calcium intakes should
be considered for peak bone mass formation. However, other researchers who compared absorption rates between adults and adolescents taking calcium supplementation found no differences between them (Andon et al., 1994).

The Saskatchewan Growth Study data further revealed that peak bone mineral accretion rate was 240g/y at age 13 for females, which is 1.6 years after peak height velocity (Martin et al., 1997). This figure was determined from cross-sectional analysis of longitudinal data. As a result of this type of analysis the peak value average was less than the true peak which would have been observed through pure longitudinal analysis i.e., aligning velocity curves on individual peak values. Bone mass appeared to follow growth curves similar to those of height and weight (Martin et al., 1997; Peacock, 1991). Two other estimates of peak bone mineral accretion have also been documented by Peacock (1991) at 280 mg/d at age 11 and 160 mg/d at age 12. There is large discrepancy between these later two values because of the different techniques used to measure BMC (metacarpal size comparison, and SPA respectively). The above data suggested that early adolescence is clearly the time of peak bone accretion rates and factors to augment this process could be important for osteoporosis prevention.

Researchers have indicated that most of the adult bone mass is accumulated during the adolescent growth period (Bailey et al., 1996; Bonjour et al., 1991; Glastre et al., 1990; Henderson et al., 1994; Kreipe, 1995; Lloyd et al., 1992; Matkovic et al., 1990 and 1994; Slemenda et al., 1994; Theintz et al., 1992) and that a positive calcium balance during this time is essential to keep up with the rapidly growing skeleton. Just how positive a balance is still controversial, but based on calcium balance studies, up to 1600 mg/d of dietary calcium intake has
been suggested to ensure a positive balance (Matkovic et al., 1992; Teegarden, 1995). This amount would be enough to cover the approximate 60 mg/d lost through the skin (Charles et al., 1983 and 1991) and obligatory urinary calcium losses. It should be noted that urinary excretion did not increase during adolescence with increased calcium intake (Matkovic et al., 1992). Urinary excretion, however, reached a maximum at age 15-16 years in a study comparing calcium metabolism in four age groups: 0-1 year, 2-8 years, 9-17 years and 18-30 years and at different quartiles of calcium intake (Matkovic, 1991). Matkovic et al. (1990) found that 170 mg/d was excreted during adolescence and considered obligatory losses, and in a later study, found urinary losses to be slightly lower at 127 mg/d for 9-17 year olds (Matkovic, 1991). This most recent value is lower than the reported value of 154 mg/d for young adults. Fecal calcium output was found to be lowest in infants and adolescents compared to young adults and children (Matkovic, 1991). There was also a strong correlation (r=0.94) between calcium absorption and retention, and even at the highest quartiles of calcium intake (1298-2721 mg/d), absorption was highest for the infants and adolescents. Weaver et al. (1995) also found that fecal and urinary excretion was less in adolescents than in adults, thus balance and absorption were significantly greater in the adolescents. This information could possibly indicate that the body's ability to use calcium during growth had not been saturated so higher intakes could prove to be beneficial for bone acquisition (Matkovic et al., 1990; Matkovic et al., 1992). A temporary deficit in bone mineral has been suggested around peak height velocity and through the peak bone mineral accretion because skeletal volume may be growing faster than bone mineral accretion (Parfitt, 1994). This again supports the possible need for higher calcium intakes during this adolescence to promote maximal genetic potential of bone accretion.
**Dietary Influences on Calcium Absorption:**

The requirement for calcium is greatest during adolescence because of the rapid growth of the skeleton. As the rate of skeletal growth (modeling) changes with age so does calcium metabolism (Matkovic, 1991 and 1992). The higher absorption rate during periods of rapid growth is an adaptation to help meet the requirements and is mediated through 1,25(OH)2D3 (vitamin D) (Matkovic et al., 1990; Matkovic, 1991; Nicolaysen et al., 1953). During rapid modeling, net calcium accretion decreases blood ionized calcium and stimulates parathyroid hormone (PTH) and thus the production of 1,25(OH)2D3 in the kidneys, and the synthesis of intestinal calcium-binding protein to increase calcium absorption (Matkovic et al., 1990; Prince, 1993; Wasserman and Taylor, 1966).

The absolute amount of calcium absorbed depends on three factors:

1) the calcium content of the food or the diet (Weaver, 1990),
2) physiological factors such as calcium and vitamin D status (Miller, 1989), needs, and age (Flynn, 1992),
3) dietary components that either inhibit or increase bioavailability through calcium absorption or urinary excretion (Dairy Bureau, 1994).

The absolute load or amount of calcium affects absorption; the more calcium ingested the lower the absorption efficiency but the absolute amount of calcium absorbed is still higher than someone with a low calcium intake and concomitant higher absorption efficiency (Cashman et al., 1996; Lee et al., 1994; Weaver and Plawecki, 1994). Heaney et al. (1990) observed a 64% calcium absorption rate with the lowest load and a 28.6% absorption with the highest load of calcium.
intake. Calcium intake spread throughout the day, as opposed to having it all at one meal or one time, maximized absorption; i.e. 500 mg supplement taken all at once yielded a 29% absorption, taking 250 mg two times daily yielded a 36% absorption, and taken in three amounts over the day yielded 40% absorption (Charles, 1992). Matkovic et al. (1990) showed a significant positive relationship between calcium intake and calcium retention in that adolescent girls ingesting high quantities of calcium had higher retention values than those with low calcium intakes, despite the fact that absorption is more efficient at lower intakes. High intake of calcium was more critical in the calcium balance equation than absorption efficiency.

Dairy foods have the highest content of calcium as compared to other food sources of calcium, and are readily absorbed (Charles, 1992). The other food sources of calcium must be considered, though, because of low intake of dairy foods, the increasing popularity of vegetarian diets in adolescent girls and the difficulty to obtain sufficient calcium from vegetarian diets (Weaver and Plawecki, 1994), and the large number of people in cultures who do not traditionally ingest dairy products. Although no statistics are available on the incidence of osteoporosis in vegetarians, of the few vegans studied, lower bone densities were observed as compared to lactovegetarians (Marsh, et al., 1988) and in vegan children aged 1-5 smaller structures and lower body weights were observed as compared to growth standards (Sanders, 1981). Lactovegetarians showed no significant differences in bone mineral content as compared to nonvegetarians (Hunt et al., 1989).

Some plant foods have a higher absorption efficiency than dairy products, but because of their high calcium content, dairy foods still deliver the largest
amounts of calcium (Weaver and Plawecki, 1994). For example, broccoli and bok choy are better absorbed than milk, but their calcium content is much less and thus they do not rate as high quality calcium sources. On the other hand, some plant sources may have relatively good calcium content but their absorption may be compromised because of inhibitors present in food, e.g., oxalic acid, phytate and fibre.

Oxalic acid forms an insoluble calcium oxalate which reduces calcium absorbed from the small intestine (Prince, 1993). Spinach, rhubarb, and beet greens are examples of plant foods high in oxalic acid. Phytate is in legumes, grains and their products, and reduce the calcium absorbed by making insoluble salts with the calcium. Phytate, as opposed to fibre, has a more negative impact on calcium bioavailability and the extent of fibre's impact on calcium balance is insignificant unless very large quantities are consumed (Leuenberger et al., 1989; NIH, 1994; Toss, 1992). Table 1.4 indicates the quality of some common calcium-containing foods based on their calcium content multiplied by their absorption efficiency. When oxalic acid and phytate-containing calcium foods are eaten with a dairy source of calcium the bioavailability is enhanced from the oxalic and phytate foods but decreased from the dairy food (Weaver and Heaney, 1991).

Vitamin D regulates the absorption of calcium so adequate amounts of it are necessary to facilitate bone formation (Francis, 1990; Health and Welfare Canada, 1990; Heaney, 1993). A two-year supplementation study with 500 mg/d of calcium and either 100 IU or 700 IU of vitamin D supplementation in postmenopausal women resulted in less bone loss in the women in the higher
vitamin D supplemented group as compared to the lesser-supplemented group (Dawson-Hughes et al., 1995). They concluded that 200 IU vitamin D was sufficient to limit whole body and spine bone loss, but not femoral neck bone loss. Common sources of vitamin D include fortified milk and sunlight of which even small quantities (10 min. daily) can stimulate enough vitamin D synthesis to meet the RDA of 200 IU. Getting this amount of sunlight is typically not a problem for adolescents, plus the enzyme system responsible for converting the precursors of vitamin D work very well during youth as compared to elderly persons, and large quantities can be stored in the liver. The major metabolite of vitamin D responsible for the active transport of calcium in the small intestine is 1,25 Dihydroxyvitamin D. With inadequate vitamin D, and thus inadequate 1,25

<table>
<thead>
<tr>
<th>Food</th>
<th>Serving</th>
<th>Calcium (mg)</th>
<th>% RNI</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>bok choy (cooked)</td>
<td>1/2 cup</td>
<td>84</td>
<td>7.6</td>
<td>fair</td>
</tr>
<tr>
<td>bread</td>
<td>1 slice</td>
<td>25</td>
<td>2.2</td>
<td>poor</td>
</tr>
<tr>
<td>broccoli (cooked)</td>
<td>1/2 cup</td>
<td>38</td>
<td>3.4</td>
<td>poor</td>
</tr>
<tr>
<td>broccoli (raw)</td>
<td>1/2 cup</td>
<td>21</td>
<td>1.9</td>
<td>poor</td>
</tr>
<tr>
<td>cheeses (firm)</td>
<td>50 g</td>
<td>353</td>
<td>32.0</td>
<td>excellent</td>
</tr>
<tr>
<td>collards (cooked)</td>
<td>1/2 cup</td>
<td>16</td>
<td>1.5</td>
<td>poor</td>
</tr>
<tr>
<td>kale</td>
<td>1/2 cup</td>
<td>103</td>
<td>9.4</td>
<td>good</td>
</tr>
<tr>
<td>milk</td>
<td>1 cup</td>
<td>315</td>
<td>28.6</td>
<td>excellent</td>
</tr>
<tr>
<td>red kidney beans (cooked)</td>
<td>1 cup</td>
<td>52</td>
<td>4.7</td>
<td>poor</td>
</tr>
<tr>
<td>rhubarb (raw)</td>
<td>1/2 cup</td>
<td>56</td>
<td>5.1</td>
<td>poor</td>
</tr>
<tr>
<td>rhubarb (cooked)</td>
<td>1/2 cup</td>
<td>184</td>
<td>16.7</td>
<td>poor</td>
</tr>
<tr>
<td>soybeans (cooked)</td>
<td>1/2 cup</td>
<td>93</td>
<td>8.4</td>
<td>fair</td>
</tr>
<tr>
<td>spinach (cooked)</td>
<td>1/2 cup</td>
<td>129</td>
<td>11.7</td>
<td>poor</td>
</tr>
<tr>
<td>tofu (with calcium sulfate)</td>
<td>100 g</td>
<td>150</td>
<td>13.6</td>
<td>good</td>
</tr>
<tr>
<td>white beans</td>
<td>1 cup</td>
<td>170</td>
<td>15.4</td>
<td>fair</td>
</tr>
<tr>
<td>yogurt</td>
<td>3/4 cup</td>
<td>292</td>
<td>26.5</td>
<td>excellent</td>
</tr>
</tbody>
</table>

Table 1.4 Quality of Various Calcium Sources  (Dairy Bureau, 1994)
Dihydroxyvitamin D, less than 10% of dietary calcium can be absorbed (National Institutes of Health, 1994), but inadequacy is usually more of an issue for infants and elderly individuals (Toss, 1992).

Other dietary substances that can influence calcium retention include protein and sodium. High protein diets increased the amount of calcium excreted in the urine (Cooper et al., 1996; Matkovic et al., 1995; Toss, 1992), however, the phosphorus content of protein foods, especially animal sources, such as milk and meat, mostly offset the loss by decreasing urinary calcium loss (Charles, 1992; Spencer et al., 1988). However, the adjustment from the phosphorus is not enough to compensate for the protein-induced calcium loss of a diet low in calcium and high in protein (Heaney, 1993). Phosphorus does decrease urinary calcium losses but it also increases the endogenous fecal calcium loss, so generally increased protein intake is associated with increased calcium loss whether or not the protein is isolated or in combination with other nutrients. Suggested as being more valuable in understanding the possible negative effects of protein on calcium balance is the calcium to protein ratio (mg:g) in the diet. A ratio of 16:1 is representative of someone ingesting current RDA values for protein and calcium. Examples from a population study of nutrient intakes and of a study on healthy adult females have revealed ratios of 9:1 and 12:1 respectively (Heaney, 1993). To put these values into perspective, dairy foods, the best food sources of calcium which also provide protein, have ratios of about 36:1 (Heaney, 1993). Recker et al. (1992) evaluated calcium and protein intakes in young women and found weak associations between calcium and bone gain (positive) and protein and bone gain (negative). When the two factors were expressed as the calcium protein to ratio, however, it became the single most important determinant of the rate of bone gain compared to the other variables.
investigated e.g., physical activity level (which followed closely behind), nutrient intake, and use of oral contraceptives (Recker at al., 1992).

Calcium need may also be influenced by dietary sodium (Matkovic et al., 1995, Williams, 1996). Matkovic et al. (1995) noted that in subjects with low calcium intakes, high obligatory calcium loss in the urine was potentiated by sodium intake and thus decreased calcium retention during growth. Sodium had a stronger influence over urinary calcium than the amount of calcium intake did.

Alcohol and caffeine have also been investigated for their interaction with calcium and thus impact on bone mass (Hernandez et al. 1993; Kiel et al., 1993). In a review article by Toss (1992) alcohol intake was shown to have a weak negative relationship to bone mass. The effects of alcohol may be manifested in decreasing appositional growth, inhibiting osteoblasts, decreasing osteocalcin and increasing serum parathyroid hormone. Calcium intake may also be lower, or the need for it higher, in alcoholics, but in the case of adolescents the concern about excessive alcohol intake is minimal. Caffeine may augment urinary calcium excretion (Charles, 1992, McCulloch et al., 1990; Toss, 1992) and decrease calcium intake because milk is being partly replaced with caffeine-containing beverages (Toss, 1992). Although the effect may be small, the influence of chronic high caffeine consumption is not known. Few studies have specifically looked at the effects of caffeine on bone mass. In a study of 101 young adults there was a nonsignificant trend for decreasing bone density with increasing coffee consumption (McCulloch et al., 1990). Consuming large quantities of coffee is also associated with lower intakes of dairy foods (which are calcium rich foods) and thus may have contributed to the lower bone densities in these subjects. In the same study, bone densities were reported as being significantly
lower for those who had five or more cups of coffee per day and smoked cigarettes, as compared to nonsmokers drinking two or fewer cups per day (McCulloch et al., 1990). Data from an age-stratified random sample of adult women, aged 44 and up, indicated that moderate caffeine intake (mean 210 mg/d) was significantly associated with bone mineral at the femoral shaft but not at the spine or femoral neck. At the femoral shaft, caffeine was associated with higher bone mineral in younger aged subjects but with less bone mineral in subjects aged 60 years and over. In this study as well, caffeine consumption was positively associated to alcohol intake and smoking (Cooper et al., 1992).

Another study involved analysis of 560 calcium balance studies on 190 women aged 34.8-69.3 years (Barger-Lux and Heaney, 1995). The researchers found that for every six-ounce serving of coffee containing caffeine, calcium balance was significantly more negative (by 4.6 mg/d). The effect was not different among those with low calcium intakes, or in estrogen deprived states, or in older individuals. They also noted that the negative calcium balance could be offset by increasing calcium intake by 40 mg for every six-ounce serving of caffeine-containing coffee. Moderate caffeine intake does not significantly affect the body's absorption or excretion of calcium (NIH, 1994), but limiting caffeine intake is often recommended in osteoporosis prevention and health awareness literature (OSTOP, 1992). With the popularity of specialty coffee shops and the large consumption of caffeine-containing cola refreshments by adolescents, adolescents could be ingesting more caffeine and less dairy products which is cause for concern. Since the studies investigating this area were on adults, specific research on adolescents should be completed to learn the effects of caffeine on calcium balance and bone mineral.
Calcium Supplementation and Bone Mineral:

Studies investigating the effects of calcium on bone mineral typically have taken one of three approaches: longitudinal intervention, cross-sectional review of calcium intake related to bone mass, or dietary recall related to current bone mass. A meta-analysis (Welten et al., 1995) of calcium intake and supplementation studies found a small but significant relationship between calcium intake and bone mass in females. There are concerns about some of the calcium supplementation studies because of poor study design and few subjects. This results in studies of low sensitivity and inability to detect any effect of calcium (Katzman et al., 1991; Welten et al., 1995). However, results have consistently shown that calcium intake and/or supplementation of 1000 mg/d or more may prevent bone loss in adults and elderly and/or positively affect bone acquisition (Anderson et al, 1993; Matkovic et al., 1990; Ruiz et al., 1995; Welten et al., 1995).

Cross-Sectional and Recall Studies:

Chan (1991) found that in female children under the age of 11 years, 70% of whom met the RDA of 800 mg/d of calcium, those consuming 1000 mg/d or more had significantly higher bone mineral content than those consuming less. For those adolescents aged 11 years or older, 63% of whom met the RDA of 1200 mg/d, no significant association with bone mineral content was noted. In a study investigating the influence of spontaneous calcium intake on bone mineral density of 151, 7-15 year olds in Paris, Ruiz et al. (1995) discovered that 93% and 84% of the children with low vertebral and femoral Z scores respectively, had calcium intakes below 1000 mg/d. No significant relationship between dietary calcium and femoral bone mineral density was found. They concluded that
calcium affected bone mineral density negatively if intakes were less than 1000 mg/d in subjects both before and during puberty.

The associations found between calcium intake and bone mineral at various sites were inconsistent. For example Ruiz et al. (1995) found no significant relationship between calcium intake and bone mineral density at the femoral neck yet 84% of the children with low intakes also had low femoral neck bone mineral density. In contrast, Valimaki et al. (1994) found no consistent association between calcium intake and lumbar spine bone mineral density but the relationship at the femoral neck was positive. They concluded that the femoral neck was more sensitive to calcium than the spine. They also suggested that there may be a threshold effect for calcium intake because no greater benefits to bone mass were seen once intake was greater than 1200 mg/d.

Matkovic and Heaney (1992) put forth this hypothesis of the threshold behaviour of calcium after reviewing their results from 474 calcium balance studies in subjects ranging in age from infancy to 30 years. Calcium balance was positively correlated with intake but a threshold at which balance no longer rose with intake was observed. For the age group of 9-17 years threshold intake was 1480 mg/d. Cumming (1990) in his meta-analysis of studies investigating the effects of calcium on bone mass also indicated the possibility of a threshold effect of calcium. Matkovic and Heaney (1992) noted that calcium intakes tended to be more often overestimated which affected the estimates for threshold balance. The threshold intake should provide enough calcium to ensure maximal skeletal retention of calcium.
**Intervention Studies:**

The best information for gaining an understanding of the effects of calcium on bone during puberty comes from long term intervention studies. Data have not supported a postpubertal effect of calcium supplementation, possibly because of confounding variables such as maturation, but have supported positive effects in children (Lee et al., 1994 and 1996). There have only been three well-controlled intervention studies of calcium supplementation in adolescents. Two studies used the same supplemental source of calcium citrate malate while the other used dairy products. Chan et al. (1995), who supplemented adolescent girls, 11 years of age, with dairy products for one year to bring their intake up to the RDA of 1200 mg/d found higher bone mineralization in these girls as compared to the unsupplemented controls. The control group (n=24) was ingesting $728 \pm 321$ mg/d while the supplemented group was ingesting almost twice as much at $1437 \pm 366$ mg/d.

In a study by Lloyd et al. (1993) 112 premenarcheal girls, mean age 11.9 years, were divided into experimental and control groups by stratified randomization to account for initial total body bone mineral density and body mass index. Experimental subjects took 500 mg/d of calcium citrate malate and controls took a placebo for 18 months. Ninety-four subjects completed the study and compliance ranged from 64-77%. Dietary intake averaged 960 mg/d for the entire study group and the supplemented group had a mean additional intake of 354 mg/d (40% more). The supplemented group had significantly greater increases than the control group in lumbar spine bone mineral density (12.5 vs. 10.5%), lumbar spine bone mineral content (26.3 vs. 23.1%) and total body bone mineral density (6.4 vs. 5.5%). They concluded that an increase in daily calcium intake to 115% of the RDA of 1200 mg/d led to a further gain in bone of 24 g per
year which translated to 1.3% increase in total body bone mineral density per year during adolescent growth. The study subjects were closely matched for maturation and controlled for exposure to estrogen, urinary calcium excretion of and blood levels of gonadal hormones. The fact that the placebo group ingested 80% of the RDA, yet did not have the gains observed in the supplemented group, indicated that higher calcium intakes, above the current RDA, could be beneficial to bone acquisition.

A later analysis of the same data Lloyd et al. (1996) showed that lumbar spine and pelvis skeletal area also had significantly higher gains (12% and 20% greater respectively) than the placebo group. The researchers also compared calcium intakes, bone gain and Tanner stage and concluded that the effects of calcium supplementation may be more pronounced in mid to late puberty stages.

Johnston et al. (1992) reported a three-year double-blind calcium supplementation study with 70 pairs of identical twins (boys and girls) ranging in age from 6-14 years. One twin acted as the control and received a placebo while the other received 1000 mg/d of calcium citrate malate. Forty-five pairs completed the study. Compliance with the supplementation declined over the three years but the additional calcium intake from supplementation averaged 719 mg/d. Dietary intakes for the two groups were almost identical (894 vs. 908 mg/d) and total intake for the supplemented group averaged 1612 mg/d and 908 mg/d for the placebo group. A significant effect on the increase in bone mineral density in the prepubertal twins was found, with increases being 2.8% greater in the spine, 3.5% greater in the greater trochanter, 3.8% greater in the distal radius, and 5.1% greater in the mid-shaft radius. Such an effect, though, was not found in the four post-pubertal twins or the 19 pairs that went through
puberty during the study. No consistent changes were noted in bone area or width. Johnston et al. (1992) concluded that prepubertal children can benefit more from higher levels of calcium intake than postpubertal children. One explanation they gave for the lack of a postpubertal effect was that it may have been difficult to detect small changes in bone mineral density during rapid growth and that increased hormones during this time may already have the bone maximally stimulated.

Andon et al. (1994) carried out a six-month calcium supplementation (500 mg/d, or 1000 mg/d of calcium citrate malate, or placebo) study on premenarcheal girls, age 11.3 years. The subjects receiving 1000 mg/d had greater increases in total body bone mineral content than the 500 mg/d supplemented group and placebo group. The gain in skeletal mass above that gained by the placebo group was 13 g and 29 g for the 500 mg/d and 1000 mg/d groups, respectively. Total intakes of calcium, dietary plus supplemental, averaged 888 mg/d, 1315 mg/d and 1618 mg/d for the placebo, 500 and 1000 mg/d supplemented groups respectively. Andon et al. (1994) concluded that because further gains in bone were noticed between the 500 mg and the 1000 mg, selecting a midpoint range of the two groups total calcium intake (1450 mg/day) would be appropriate for the RDA. This value was also consistent with the adolescent threshold intake of 1480 mg/d as calculated by Matkovic and Heaney (1992). Matkovic et al. (1990) had previously supplemented twenty 13-14 year olds with milk or calcium supplements for 2 years and similarly found that bone gain tended to be greater in the high calcium (1640 mg/d) versus low calcium (<850 mg/d) intake groups.

These researchers have indicated that modest effects of dietary intervention were difficult to detect with small subject numbers, a wide age range, and a wide
maturation level range (Andon et al., 1994). Larger intervention studies with closely matched subjects are needed to determine more clearly the effects of calcium on bone during adolescence as well as the persistence or long term benefits of supplementation after it is withdrawn.

Most supplementation studies have either used calcium citrate malate or carbonate as a supplement source. Andon et al. (1994) compared absorption rates of these supplements found in three studies. They found that citrate had a consistently higher absorption rate than carbonate. For example, studies that compared the two types of supplements found absorption rates of 36, 41, and 37% for citrate and 26, 27, and 30% for carbonate respectively (Andon et al., 1994). The first two studies were on adolescent subjects and the later one was on young adults. Carbonate has been described as having an absorption rate similar to that of dairy products (Andon et al., 1994). Miller et al. (1988) also compared absorption rates of calcium carbonate and calcium citric and malic acids in 12 adolescents (six males and six females). These researchers noted higher absorption rates of 36.2% with the citric and malic acids, as compared to 26.4% observed with the carbonate.

A few researchers have recently started asking the question that if supplementation is withdrawn, do the benefits gained remain? A few retrospective studies in the 1970's and 1980's suggested that the effects of calcium on bone gain in childhood and adolescence would persist into adulthood (Andon et al., 1994). It is generally thought that intakes need to remain high (near the RNI/RDA) in order to retain the benefits gained from supplementation (Teegarden, 1995). This was demonstrated in two studies of long-term supplementation in peri- and postmenopausal women which concluded that
continued supplementation of 3-4 years sustained the reduction in rate of bone loss demonstrated in the first two years of supplementation (Elders et al., 1994; Reid et al., 1995). Three studies have investigated the consequences of calcium-supplementation withdrawal on bone mineral in children and adolescents (Lee et al., 1996; Lloyd et al., 1996; Slemenda et al., 1993). Lee et al. (1996) found that the benefits of 18 months of calcium supplementation were reversed after 18 months of being off calcium supplementation, e.g., the percentage of bone gain was now similar to the original unsupplemented group, and absolute values of bone mineral content were not any higher in the previously supplemented group than in the unsupplemented group. The subjects in this study were 8.5 years of age at the start of the follow-up period. Slemenda et al. (1993) found that three years of calcium supplementation in monozygotic twins (aged 6-14 years) resulted in the supplemented twin having significantly higher rates of bone mineral density gain (+3% average) over the unsupplemented group. After three-years follow up of no supplementation, however, the differences in bone mineral density between the originally supplemented children and controls were not significant (Slemenda et al., 1997) but both groups continued to increase in bone mass during this time. The researchers concluded that supplementation had very little, if any residual benefit three years later.

Lloyd et al. (1996), who had implemented a calcium supplementation study on 11 year old girls with Andon et al. (1994) and found in the first two years of the study greater rates of bone acquisition in the supplemented group (Lloyd et al., 1993), continued with the randomized cross-over design study for four years to investigate the persistence of enhanced bone gain from earlier calcium supplementation. The study group was divided into four treatment groups: i) four years of placebo, ii) two years of calcium supplementation followed by two
years of placebo, iii) two years of placebo followed by two years of supplementation, and iv) four years of supplementation. When the subjects were about 17 years old they had been post intervention for at least one year and total body bone mineral contents were not significantly different between any of the groups. These results showed that two out of four years of supplementation of 500 mg calcium per day had little residual effect, a similar finding to Slemenda et al. (1997). However, there may be long-term positive effects at certain bone sites, or a positive effect may persist if supplementation is continued.

In summary, there is evidence that the need for calcium is greatest during the rapid growth phase and peak bone mineral accretion period of adolescence as indicated by the data from the Saskatchewan Growth Study. There is also evidence that the body may have physiological mechanisms in place to help compensate for this increased need, such as maintaining lower levels of urinary excretion, as opposed to it increasing with greater calcium intake, and by possibly increasing the absorption efficiency of calcium. As shown by the intervention studies, a positive relationship between calcium intake near the RDA (1200 mg/d), or slightly above, and greater bone acquisition exists, as opposed to lower intakes (below 1000 mg/d). Intakes well above the RDA seem to pose no added benefit indicating the possible threshold nature of calcium and brief periods of calcium supplementation may have no long-term benefits for bone mass accretion. Many factors affect the intake and bioavailability of calcium which should be considered to maximize the amount available for skeletal use during adolescence. The limited amount of data from well-controlled intervention studies necessitates more research to clarify the effects of calcium on bone accretion during adolescence, differences in calcium
metabolism and absorption during this time of increased need, and the long term effects after periods of high calcium intake.

iii) Interaction Between Physical Activity and Calcium

In the National Institutes of Health Consensus Statement on optimal calcium intake (1994) it was briefly mentioned that a beneficial relationship may exist between calcium intake and physical activity, meaning that the two factors together may have a synergistic effect on bone gain, but the limited research in this area prevented any concrete conclusions. An interaction between physical activity and calcium could result in different changes in bone mineral than expected by either one of the factors alone. Studies on elderly populations have failed to show a relationship between the two factors together and bone mass (National Institute of Health, 1994). Anderson et al. (1993) suggested in a review article that when combined with physical activity, adequate calcium intake appeared to have a more positive effect on forearm bone mineral, which was the only site measured in this study.

A possible mechanism of how physical activity and calcium intake interact is that more active individuals require more energy and, therefore, some of their extra caloric intake may be in calcium-containing foods. This could facilitate intakes that meet the RNI and thus positively affect bone mass. However, some researchers have found no significant relationship between increased physical activity and increased calcium intake (Kelly et al., 1990). A negative consequence of the increased activity related to calcium, is the potential for greater calcium losses through sweat (Toss, 1992). This issue was investigated recently in college male basketball players (aged 18-22 years). What prompted the study was the quest for an explanation for low bone mineral density and/or
content in male athletes in light of the fact that decreased estrogen levels, which can possibly explain why female athletes often have decreased bone mineral content and density, is not a factor affecting male athletes.

Klesges and colleagues (1996) had three purposes of their study: 1) to determine if intense training had negative consequences on bone mineral content, 2) to determine calcium losses through sweat and urine, and 3) to intervene with calcium to see if bone mineral content could be increased. The results showed that the 11 players lost 3.8% of total bone mineral content from preseason (September) to midseason (January), then insignificant decreases were observed from midseason to post season (March). Calcium losses through sweat and urine were evaluated three days out of a ten-day training period and compared to calcium intake and total bone mineral content changes over this time. Calcium losses on the first day were reported as 624 mg and decreased to 179 mg on the last training day, however the training intensity was much lower as well. Dietary intake over 2000 mg/d was significantly related to increases in total body and leg bone mineral content whereas intakes less than 2000 mg/d were associated with losses.

The calcium supplementation phase of the study took place again from preseason to midseason and the calcium dosage was based on algorithm considering the subjects' intake and how much bone mineral content they lost during this period the year before. Supplementation ranged from 500-2000 mg/d in the form of a calcium citrate tablet (1800 mg) and/or a non-dairy calcium fortified drink (600 mg). An increase in bone mineral content of close to 2% was observed preseason to midseason and terminated any losses. The authors concluded that exercise may promote increased bone mineral content.
provided calcium intake is high enough to compensate for dermal losses of calcium due to intense training. The results appeared very positive and suggested an additive benefit of calcium and exercise together, however, they did not test for any interaction in their analysis and their methodology has since been criticized (Barr and Heaney, 1997). These criticisms, which included comments about inaccuracies in collection of sweat samples, errors in calculations of sweat calcium losses indicating a possible overestimation, and gains in bone mineral content despite negative calcium balances, greatly reduce the validity of the findings and necessitate further explanation and analysis to be able to fully understand the implications.

Physical activity, regardless of calcium intake, however, may be a more important factor than calcium alone in bone mineral acquisition (Anderson et al., 1993; Fehily et al., 1992; McCulloch et al., 1990; Valimaki et al., 1994; ). Anderson et al. (1993) found in their long-term study of adolescents that physical activity was the most significant contributor to bone mass. It was also suggested that physical activity could partially compensate for low dietary calcium intake. However, in some anorectic individuals, where high levels of exercise and low calcium intakes are common, the exercise could not overcome the negative consequences of low calcium and low energy intake. This may have been due to the changes in hormonal level (Snow-Harter, 1994), but could also be indicative of an interaction effect.

The interaction of genetic and environmental influences on peak bone density has been investigated (Salamone et al., 1996) and the authors suggested that calcium intake could have a potentiating effect on physical activity or genetic potential to exert their effects on bone accretion. However, no studies, set up in
a 2x2 design intervening with both exercise and calcium, have been published using adolescent subjects to determine the possible interaction or additive effects. A study in postmenopausal women was set up in this fashion but failed to report on interactions. Specker (1996) reviewed published exercise trials, which also reported calcium intakes, to investigate what evidence there was for an interaction between these two variables. The studies reviewed were on the adult population and reported bone mineral values for the lumbar spine and distal radius. She concluded that i) physical activity was beneficial to bone mineral density provided calcium intakes were high (>1000 mg/d), ii) there was no effect of calcium in exercise or control groups if intakes were less than 1000 mg/d, iii) the exercise groups consistently had greater increases in lumbar spine density than control groups, with both groups receiving increasing amounts of calcium, and iv) there was no positive effect of calcium on bone mineral without exercise.

Specker et al. (1996) also completed a study looking at the interaction of calcium and exercise in infants and found results which agreed with the general conclusions from her review paper. Seventy-five infants were randomized into a fine or a gross motor activity program for 12 months and calcium intake was monitored. A significant three-way interaction between physical activity and bone mineral accretion (over the 12 months) and calcium intake was found. Infants in the low calcium intake category who participated in gross motor activities had lower bone mass accretion than those in the fine motor activity group. In infants with high calcium intakes there was no effect of activity on bone accretion. These results suggested, and agree with other researchers'
conclusions (Anderson, 1993; Klesges et al., 1996, Specker et al., 1996) that participation in strenuous physical activity could be detrimental to bone mass accretion if intake of calcium is inadequate. Mazess and Barden (1991), who observed women aged 20-39 on various lifestyle factors over a two-year period found no significant interaction between the effects of calcium intake and physical activity on bone mineral density. Not enough information, however, was given about how they actually statistically tested for an interaction effect.

From this review it appears that a positive effect of physical activity may only exist when calcium intake is above 1000 mg/d and that high calcium intakes are only beneficial to bone when combined with physical activity. There is no published data, however, on whether these two factors affect bone mineral differently together than they do alone. The limited data make it impossible to draw strong conclusions regarding the interaction between these two modifiable lifestyle behaviors. Controlled intervention studies with both independent variables (calcium and exercise), and appropriate analyses to test for an interaction between them, must be completed in the adolescent population. This information could have great implications for the recommendations for attainment of peak bone mass.

iv) Hormones

Estrogen acts as an inhibitor of bone resorption, therefore, situations causing chronically low levels of estrogen place those individuals at greater risk for osteoporosis (Francis, 1990). Estrogen status is one of the most important determinants of bone mass in women (Armamento-Villareal et al., 1991; Sowers et al., 1990; Toss, 1992). In women aged 19 to 40 years old estrogen status (calculated from age of menarche, length of menstrual cycles, and use of oral
contraceptives) was the only significant independent determinant of vertebral bone density when considering age, body mass index, parity, lactation, physical activity, sunlight exposure and dietary calcium and vitamin D intakes (Armamento-Villareal et al., 1992). The sudden increase in bone loss after the onset of menopause can mostly be attributed to the decrease in circulating estrogen. Premenopausal bone loss is approximately 2-3% per decade and increases to 3-10% per decade postmenopause, though there is great individual variability (Martin and Brown, 1989). Estrogen replacement has been successfully used to prevent bone loss in postmenopausal women (Lindsay, 1993; Maxim et al., 1995; Notelovitz et al., 1991). Menopause is not the only situation in which estrogen levels are low. Amenorrhea, irregular menses and delayed menarche, arising from conditions such as disordered eating, extreme weight loss or excessive exercise, all affect estrogen status of younger females.

Studies investigating the hormonal status of adolescent girls have shown that those who had the lowest estrogen scores also had the lowest bone density and a higher age of menarche (Baer et al., 1992; Dhuper et al., 1990; Martin and Bailey, 1987). Over a two-year period Dhuper et al. (1990) studied 43 females, aged 13-20 years, who had varying degrees of estrogen exposure. Twenty-four girls who reached the age of 18 years by the end of the two years were divided into groups of high, medium and low estrogen exposure. Bone mineral density of the wrist and spine, measured by SPA and DPA respectively, was lowest in the low estrogen exposure group. These girls had the lowest weight to height ratio, lowest weight, highest age of menarche and the highest amount of fibre in their diet. Low bone density of the foot was also found in the group with lowest estrogen exposure and higher activity levels. The authors suggested that bone mass in active adolescents is affected by the lack of estrogen (Dhuper et al.,
Delayed menarche (primary amenorrhea), which postpones the protective effect of estrogen, is common in highly active girls, especially those competing in endurance sports such as gymnastics and track, as well as in eating-disordered girls. Some researchers have noted higher bone densities in those women having an earlier age of menarche as compared to a higher age (Fehily et al., 1992). Ito et al. (1995) also found that earlier menarche was related to higher lumbar spine bone mineral density in 519 females ranging in age from 21 to 74 years, with the association being stronger in premenopausal women. Lower bone density was characteristic of highly active, amenorrheic girls suggesting that activity on its own was not capable of maintaining bone density when estrogen levels were deficient (Baer et al., 1992; Dhuper et al., 1990; Martin and Bailey, 1987).

Primary and secondary amenorrhea and oligomenorrhea are common in athletes following intense endurance training programs, especially if combined with low body weight and low caloric intake, and in adolescents with the eating disorder anorexia nervosa (Bachrach et al., 1991; Seeman et al., 1992). The resulting lower levels of circulating estrogen increase bone resorption and could, therefore, predispose these athletes and/or anorectics to lower bone density and osteoporosis later in life (Bachrach et al., 1991; Baer et al., 1992; Duerksen, 1996; Hergenroeder, 1995; Lloyd et al., 1988; Martin and Bailey, 1987; Polaneczky and Slap, 1992; Seeman et al., 1992; White et al., 1992). This situation can be critical especially since anorexia most often begins during adolescence and the earlier the onset of the disorder the greater the fracture risk later because of greater deficits in bone (Seeman et al., 1992). With the combination of poor nutrition, low calorie and low calcium intake, bone accretion is not promoted (Bachrach et al., 1991; Seeman et al., 1992). Adolescent female runners with
secondary amenorrhea maintained significantly decreased estradiol levels over a 12-month duration as compared to eumenorrheic runners, and calcium and vitamin D supplementation offered no compensation, in terms of effects on bone mineral, for the reduced estradiol levels (Baer et al., 1992). A study of 65 young female patients (age 20-30 years) with anorexia nervosa reported lower femoral and spine bone densities, lower weight, fat mass and lean mass than the healthy control group (Seeman et al., 1992). It has been documented that even though recovering anorexics show improvement in bone density, the deficits may never be completely recovered (Bachrach et al., 1991). Excessive exercise is common in patients with this disorder yet it may not offer any protective effect without the complement of optimal levels of circulating estrogen (Seeman et al., 1992).

The use of oral contraceptives can alter the levels of circulating estrogen and has been investigated as a protective element for young women with estrogen deficient conditions. A positive correlation between bone density and oral contraception has been noted (Seeman et al., 1991; Ulrich et al., 1996). A study on prior oral contraceptive use of 239 postmenopausal women indicated higher bone densities in those who had used them for six or more years. There was no significant difference in the age of onset of menopause yet users would have entered this state with more bone mass (Kritz-Silverstein and Barrett-Connor, 1993). Another study of women aged 47.9-59.6 years found slight but significantly higher bone mineral density in the femoral neck and lumbar spine among past oral contraceptive users, however, the subjects were different in many other lifestyle behaviors which could have confounded the results (Tuppurainen et al., 1994). Another study which involved two years of observation of various lifestyle factors in women aged 20-39 found no significant associations with the use of oral contraceptives and bone mineral density of the
radius, femoral neck or spine, measured by SPA and DPA (Mazess and Barden, 1991). Longitudinal and dose-response studies would offer more information of the short and long-term effects of oral contraceptive use especially since the estrogen content of newer oral contraceptives is much lower than in the past.

Estrogen is well documented as an important factor in bone mineral retention in adults and as therapy for postmenopausal women. More recently progesterone, which is linked with estrogen secretion during the normal human menstrual cycle, has been given more attention as to its role in bone metabolism. Similar to estrogen, when menstruation stops progesterone levels also decrease (Prior, 1990). Prior (1990) has suggested in a review article that progesterone is active in bone metabolism, alters bone turnover, or acts directly on the osteoblast to promote bone formation. The value in estrogen therapy is in its effect of decreasing bone resorption, but there is little, if any effect on bone formation. Progesterone may prove to be valuable in bone formation. However, other researchers found weak effects of a closely progesterone-related steroid as compared to the stronger effects of estrogen in postmenopausal women (Cundy et al., 1994) Bone mineral density was actually reduced in long-term users of the injectable contraceptive. More research on the effects of progesterone, both in the adult and adolescent population, will need to be completed in order to draw conclusions regarding its importance for bone mineral accretion.

The fact that peak bone mineral accrual is around the time of menarche in adolescent girls (Bailey et al., 1997) may also be suggestive of estrogen's important role, though many other growth factors are operative at this time. Diet and physical activity patterns affect menstrual functioning, and thus circulating hormones, which affects bone mineralization during the pubertal
growth spurt (Corvol et al., 1992; Hill et al., 1980). More research into the effects of, or lack of, estrogen on bone mineral accrual in conjunction with other lifestyle factors such as exercise and calcium intake needs to be carried out in adolescent girls (Hergenroeder, 1995).

v) Smoking

Smoking has been suggested as having negative effects on bone density. Lower bone densities have been observed in daily smokers in some studies (Krall and Dawson-Hughes, 1991; McCulloch et al., 1990 and 1991; Toss, 1992) but not in others (Daniel et al., 1992; Toss, 1992). Postmenopausal smokers were also found to have significantly lower fractional calcium retention than nonsmokers after a two-year calcium supplementation study (Krall and Dawson-Hughes, 1991). A study of 84 healthy pre- and postmenopausal women indicated lower bone mineral content in heavy smokers as compared to moderate or nonsmokers, but no difference in the rate of bone loss after menopause (Slemenda et al., 1989). Daniel et al. (1992) found no significant difference in bone density between female smokers and nonsmokers (age 20-35 years), however, they did find that levels of sex hormone-binding globulin (SHBG) were significantly higher in smokers. The higher SHBG significantly lowered the estradiol index (estradiol/SHBG) which significantly affected whole body bone mineral density. Another study also found higher SHBG levels and significantly lower bone mineral density in the femoral neck and intertrochanter region in premenopausal women who smoked (Ortego-Centeno et al., 1994). A two-year observational study of women, aged 20-39 years, showed significantly lower spine bone mineral densities, and a tendency for lower densities at other measured skeletal sites in smokers as compared to nonsmokers (Mazess and Barden, 1991).
A more recent prospective study involved an 11-year follow-up on lifestyle factors which could have affected bone mineral density on subjects who were adolescents, aged 9-18 years, initially (Valimaki et al., 1994). Using end-point DXA measurements, analyses showed an inverse correlation between hip and spine bone mineral density in males who smoked during adolescence and a trend for lower bone mineral densities was noted as smoking index increased. Femoral neck bone mineral density was 9.7% lower in male smokers as compared to male nonsmokers. There were no consistent associations for females between smoking and bone mineral density, but the method of determining the smoking index could have accounted for this (Valimaki et al., 1994). Smoking index was estimated three times in the eleven years by assigning a score of one to those who answered yes to daily smoking and a zero to those subjects who answered no, then the sum of the three testing sessions determined the smoking index. The index was not very discriminative because it did not account for those subjects who may have smoked numerous cigarettes on one day then few the next day, or those who smoked only at certain social occasions. Body weight, exercise and age were the independent predictors of femoral neck bone mineral density in women and accounted for 36% of the variance. Fehily et al. (1992) found no effect of smoking on bone mass, but thought that the female subjects had not been smoking long enough for any negative effect to show. In a study of young women, aged 20-35, bone mineral density was lower in those who smoked daily as compared to those who did not (McCulloch et al., 1990). Toss (1992) found a negative correlation between smoking and calcium intake which, therefore, could indirectly affect bone acquisition in adolescents because of decreased calcium intake.
A cross-sectional study of 41 pairs of adult female twins, aged 27-73 years, found that the bone density of the twin who smoked more heavily ranged from 0.9% - 2% lower at various bone sites (Hopper and Seeman, 1994). The authors concluded that women who smoked a pack per day could have a deficit of 5-10% in bone density by the time they reach menopause, which is sufficient to increase osteoporotic fracture risk by about 25-50% (Johnston and Slemenda, 1993).

Through a three-year follow-up study on a cohort of adults, aged 50 years and over, researchers found that the relative risk for hip fracture in female smokers, with a set body mass index of 25 kg/m$^2$, was 1.5. This risk for hip fracture, which was adjusted for leanness and physical inactivity, increased to 3.0 with leaner females (body mass index of <20 kg/m$^2$) (Forsen et al., 1994). Similarly, greater bone deficit was found in non-obese smokers' metacarpals than in those of obese smokers in a cross-sectional study of 60-69 year old females (Danieli, 1976).

The tendency towards lower body weight, lower peak bone mass, less physical activity and earlier menopause of smokers puts them at an increased risk for fractures and osteoporosis (Lawrence, 1996; Slemenda et al, 1989; Toss, 1992). Smoking and second-hand smoke may contribute to lower body weight and delayed menarche in adolescents resulting in lower levels of circulating estrogen which could hinder attainment of peak bone mass (McCulloch et al., 1990; Slemenda et al., 1989).

Further investigation is required to clarify the effects of smoking, but as a preventive measure smoking is discouraged, especially for adolescents (Francis, 1990; McCulloch et al., 1990; Slemenda et al., 1989; Valimaki et al., 1994). Unfortunately it is the female adolescent population where smoking is on the
increase (Greaves, 1987; Green, 1997). The only age group where females were more likely to smoke than males was between age 15-24 years as documented in the Canada Fitness Survey (Stephens and Craig, 1990). Peer pressure, weight control, social situations and personal beliefs may contribute to the incidence of smoking (Rafuse, 1993; Tonkin, 1994). The survey also noted that more active adolescents are less likely to smoke.

vi) Heredity
Studies addressing family resemblance in bone density and shared environmental factors have shown a strong familial influence on bone density, indicating that up to 46-62% of variance in bone density could be accounted for by hereditary factors (Krall and Dawson-Hughes, 1993; Slemenda et al., 1991). One review indicated that genetic factors could contribute up to 80% of the variance in bone density (Kelly et al., 1990). Bone density is greater in black children than in white children demonstrating the effects of race on bone density (Bell et al., 1991) and the necessity to study homogeneous groups, in terms of race and ethnicity, when looking at bone mineral changes (Patel et al., 1992; Villa, 1994). Family history of osteoporosis was associated with lower bone mineral density in men and women aged 60-89 years (Soroko et al., 1994). The relative risk for osteoporosis was highest in those whose fathers had a history of osteoporosis (Soroko et al., 1994). Though variance in bone density is partially due to hereditary factors there are many environmental factors which ultimately affect the acquisition and maintenance of bone mass, such as physical activity, calcium intake, and smoking (Martin and Bailey, 1993; Heaney, 1992; Krall and Dawson-Hughes, 1993; McCulloch et al., 1992; Slemenda et al., 1989) as discussed earlier in this review. The addition of lifestyle-factor variance and genetic variance equals more than 100% indicating some interaction or shared
variance between environmental and genetic influences on bone mass (Brandi et al., 1994; Kelly et al., 1990; Smith et al., 1973).

Studies involving twins and mother-daughter pairs provide the best evidence of the genetic influence on bone mass. Pocock et al. (1987) studied monozygotic and dizygotic twins, mostly pre- and postmenopausal females, for genetic influences at various bone sites. Bone mineral density was more highly correlated in the monozygotic twins than in the dizygotic twins at the spine, proximal femur and forearm. The genetic contribution was less in the femur and forearm than the spine which suggested that bone mass at these sites may be more affected by environmental factors than by genetics (Pocock et al., 1987). Slemenda et al. (1991) carried out a similar study with results in agreement with Pocock et al. (1987) and an earlier study by Smith et al. (1973). Monozygotic twins had higher interclass correlations than dizygotic twins in both pre- and postmenopausal women. The authors suggested that monzygotic twins shared more similar environments than dizygotic twins and that gene interaction was likely because of the unrealistically high heredity estimates. Therefore, the estimates for heredity are probably too high and should be interpreted cautiously (Brandi et al., 1994; Slemenda et al., 1991).

Familial resemblance in bone mineral density has been documented through a number of studies which consistently showed high correlations within families (Krall and Dawson-Hughes, 1993; Lutz and Tesar, 1990; McKay, 1995; McKay et al., 1994; Seeman et al., 1994). The Z scores for femoral neck of the daughters of women who had had a hip fracture were significantly reduced by half a standard deviation and would likely increase their risk for hip fracture (Seeman et al., 1994). McKay et al. (1994) looked at standardized lumbar spine and
proximal femur bone mineral density Z scores for mother-daughter pairs, mother-son pairs, mother-grandmother pairs and mother-grandmother-daughter pairs. Correlations, ranging from 0.41-0.57, for each of these sites were significant between mother-grandmother and mother-daughter pairs, and these correlations improved if Z scores were maturity based as opposed to chronological-age based. There was strong familial patterning amongst three generation comparisons in 13/18 families for the hip, and 12/18 families for the spine. Krall and Dawson-Hughes (1993), who also investigated familial pairs, found correlations ranging from 0.22 to 0.52 between mother-daughter pairs at five different bone sites. Lutz and Tesar (1990) also found significant correlations between mother-daughter pairs for proximal femur and lumbar spine sites measured by dual-photon absorptiometry. Another interesting finding in this study was that correlations were higher between premenopausal mothers as compared to postmenopausal mothers at the trochanter. The authors suggested that the genetic influence on bone mass had two components, one affecting peak bone mass and the other affecting menopausal bone loss (Lutz and Tesar, 1990).

The genetics of low bone mass and osteoporosis is a complex issue and challenging to investigate (Brandi et al., 1994), however, genetic studies thus far have clearly shown a strong familial resemblance in bone density. The interactive effect of environment and genetics determine peak bone mass. Genetics sets the limits and environmental conditions dictate the extent to which those limits are met. The fact that heredity did not account for all of the variance in bone mass, and that evidence suggested an interaction with environmental factors in the demonstration of one's genetic potential for peak bone mass, emphasize the importance for further investigation into the influence of
heredity. However, attention to the lifestyle factors affecting peak bone mass may have greater implications as these factors are modifiable.

1.6 Bone Size and Skeletal Area

Most studies investigating the effects of certain lifestyle factors on bone use bone mineral content and density as the dependent measures and are interpreted to reveal possible fracture risk. However, bone size, geometry and skeletal area also play a key role in contributing to bone strength and thus fracture risk (Lloyd et al., 1996; Snow-Harter, 1991). Bone size and geometry can influence the resistance of bone to fracture independently of bone mineral density yet most studies do not correct for differences in bone size (Bhudhikanok et al., 1996). A smaller cross-sectional area of bone is more likely to fracture than a larger one.

In a review article Snow-Harter (1991) explained that the arrangement of bone mass around the bone axis affects bone strength. For instance, two bones of equal mass could have different strengths if one is of greater size (diameter) due to more of its bone mass being located farther away from the bone bending axis. Stresses created within the bone by loading can alter the shape and density of bone by stimulating external remodeling. This can result in an increase in bone size. During aging the periosteal formation in the long bone, which can alter bone size, partially compensates for the strength loss due to endosteal bone and matrix loss (Lloyd et al., 1996; Snow-Harter and Marcus, 1991).

There has only been one published study using bone to compare adolescent female bone changes during a calcium supplementation intervention (Lloyd et al., 1996). The two-year study investigated the effects of 500 mg calcium
supplementation on 112 premenarcheal girls. Calcium was found to have significant positive effects on bone mineral density and content, as well as bone area in the whole body, pelvis and lumbar spine.

Other study results have revealed the importance of evaluating bone size as a comparison tool for bone, especially during the growth periods of childhood and adolescence. For example, it has been suggested that gender differences noted in children and adolescents may be due to bone size rather than bone density (Gilsanz et al., 1988; Lloyd et al., 1996; Ross et al., 1996). The possible effects of body weight, puberty stage, physical activity, and calcium could be mediated by changes in bone size as opposed to density (Bhudhikanok et al., 1996), therefore, it would be valuable to measure bone size in studies researching the effects of these variables. In a comparison study between 9-26 year old Asian and Caucasian females Bhudhikanok et al. (1996) concluded that racial differences in bone mineral density were fewer when BMAD was used, indicating that bone size may be the factor in bone mass differences. Katzman et al. (1991) who investigated the anthropometric correlations of bone mineral acquisition in adolescent girls, concluded that 96% and 99% of changes in the femoral neck and total body bone mineral, respectively, reflected an increase in bone dimensions.

Bone mineral apparent density (BMAD), as discussed earlier in this review, is based on a estimated bone volume, considering bone thickness as well as projected area, and results in a three-dimensional bone mineral density. Tabensky et al. (1996) investigated and compared the inaccuracies in bone dimension measurements and their use as surrogates of bone strength in lumbar vertebrae (in vitro). All of the measures tested, which included bone breadths using calipers, densitometry, as well as various correction techniques to
account for bone size by estimating a volume density, resulted in errors in height, width and depth of bone. The densitometry and Carter et al. (1992) methods overestimated volume and, therefore, underestimated density. The calipers underestimated volume and, therefore, overestimated density. Despite the small errors in measurement the researchers concluded that all methods were valid and comparable surrogate measures of breaking strength in bone (Tabensky, 1996). Using bone size and skeletal area measurements, especially during growth and in intervention studies, could be valuable in revealing information about positive bone changes. A change in bone size, which increases bone strength, would decrease risk of fracture even if there was no increase in bone density. It may be more likely to see increases in size, due to growth and/or intervention, during adolescence than it would be to see increases in density.

1.7 PRECEDE PROCEED Model of Health Promotion Program Planning

One of the biggest problems with previous school-based physical and health education/promotion programs is failure to follow a theory-based planning model (Dopp, 1986; Dwyer et al., 1991; Floyd and Lawson, 1992; Green and Kreuter, 1991). One model which has been well-tested and used in over 600 published health promotion applications is called the PRECEDE PROCEED model (figure 1.4). The model was originally developed by Green and is fully explained in the second edition of the book by Green and Kreuter: Health Promotion Planning: An Educational and Environmental Approach (Green and Kreuter, 1991).

The PRECEDE PROCEED model is a health promotion planning and evaluation model aimed at assisting in the development of health education, intervention...
Figure 1.4  The PRECEDE PROCEED Model for Health Promotion Planning and Evaluation (Green and Kreuter, 1991, p. 24)
programs, either to maintain and encourage a behavior or living condition which is associated with enhanced health, or to inhibit a behavior or living condition associated with increased risk of illness or injury (Green and Kreuter, 1991). The model can be used for other education topics as well, not just health education but the focus of this research is health education. The PRECEDE components of the model help identify the numerous factors that influence health status, and among those and their causes, the ones that should be the focus of an intervention program. It also helps set the program objectives and criteria for evaluation. The PROCEED components of the model outline the steps for developing policy, implementing and evaluating the program and its outcomes. The model reflects continuous and comprehensive planning.

PRECEDE has been tested for its predictive validity and evaluated in numerous field and clinical trials whereas PROCEED is a newer addition to the model with fewer applications and field tests (Green and Kreuter, 1991). The initial motivation behind the development of the model stems from the fact that most health promotion planners either have an intervention strategy already in mind or have chosen a health issue or target group without thoroughly analyzing the situation.

The model usually begins with the end in mind. In other words, the desired outcomes are often known first, then the phases of the model help identify what causes those outcomes. Nine phases constitute the planning and evaluation model.
Phase 1 - Social Diagnosis

This phase involves identifying the major concern or social problem affecting quality of life of a target population or community (figure 1.5). People's perceptions of their health and behavior are molded, changed and maintained by their interaction with their immediate environment. Therefore, it is helpful if these perceptions are known before an intervention program is designed and involving the community in the identification of the problem is an ideal way to learn the perceptions and gain their support for the program (Eriksen et al., 1988). There is a reciprocal relationship between health and well-being; each can influence the other. Well-being and quality of life are difficult both to measure and to define. Adjustment to, and satisfaction with life experiences, resources, social indicators and descriptions of the environment can give some indication of the quality of life.

The three steps for the social diagnosis phase are to:

1. Study the community's problems, needs, and goals.
2. Report the presumed causes of the problems or determinants of the desired goals.
3. Rank in terms of priority the list of problems, needs and/or goals based on perceived importance, potential changeability, and development of quantifiable goals and objectives.

These three steps are also applied specifically for phases 2, 3, and 4 of the model.

Examples of strategies for determining the social or health problem are: key informant interviews, community forums, focus groups, nominal group
Figure 1.5 Phases 1, 2 and 3 of the PRECEDE Model with examples of relationships, indicators, and dimensions of factors that might be identified in the diagnostic process (Green and Kreuter, 1991, p. 27).
processes, surveys, estimates from national data, archival research, and social indicators. Some of these are further explained in Health Promotion Planning (Green and Kreuter, 1991).

Eriksen et al. (1988) outlined eight principles of changing health behaviour which are inherent in the PRECEDE PROCEED model. These principles included: diagnostic, hierarchical, cumulative learning, participation, situational specificity, multiple methods, individualization, and feedback. The first principle, the diagnostic principle, determines illness, causes and interest as does the social diagnosis phase of the PRECEDE PROCEED model. The fourth principle, that of participation, states that the success of health education programs depends on involving people in defining their needs, priorities and solutions (Eriksen et al., 1988). Having the community or target population involved in identifying the health concern helps in forming partnerships, accessing resources, and fostering support for the health promotion program.

ii) Phase 2 - Epidemiological Diagnosis
This phase helps specifically identify a clear relationship between a particular health problem and the social/quality of life issue defined in phase 1. Data and epidemiological findings are used to measure the health problem in terms of morbidity, disability or mortality. The five "D's", death (mortality), disease (morbidity), dysfunction (disability), discomfort and dissatisfaction are used as indicators of health status in a population. Examples of specific indicators or dimensions measured within these categories are fitness level, functional level and incidence (figure 1.5). Etiology of the health problem is also addressed.
Community or target population statistics can be compared to other communities or norms to determine the relative importance of the problem. There are two approaches in relating the social assessment to the epidemiological assessment:

A. reductionist - works from the broad social problem to assessment of the health component that contributes to the problem.

B. expansionist - starts at a specific health problem and works outward to determine the social consequences of the problem before continuing with the next phase of the planning model.

Measures such as incidence, prevalence, cost-benefit analysis, age-adjusted rates, and sensitivity analysis help determine the seriousness of the health problem. Etiology or determinants (risk factors) of health are also identified in this phase. A list of genetic, behavioural and environmental risks, both changeable and unchangeable, is compiled. Based on research and consensus data the risk factors are weighed. Relative risk, risk ratio, odds ratio, and dose-response relationship are measures which can help identify the risk factors and serve to focus on an intervention program plan. Once these have been identified then health objectives are stated indicating who will receive the program, the health benefit to be received, how much of it, and by when or for how long.

iii) Phase 3 - Behavioural and Environmental Diagnosis

Through this phase specific environmental factors and behaviours that may be associated with the health problem are determined. A systematic approach of identifying, ranking and choosing target factors most pertinent to determining
health and quality of life is taken. A common term used to describe such a factor is risk factor. Non-behavioural factors and others which cannot be modified must be considered as well in the overall diagnosis to assist in ranking and choosing interventions. This phase emphasizes the fact that health is determined by many factors. An example of a behavioural indicator for a health problem may be a sedentary lifestyle. A decrease in mandatory school physical education classes is a possible environmental indicator of a health problem (figure 1.5).

Green and Kreuter (1991) outlined five steps each for behavioural and environmental diagnosis:

<table>
<thead>
<tr>
<th>Behavioral</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Separate behavioral and non-behavioral causes of the health problem.</td>
<td>Eliminate non-behavioural causes that cannot be changed.</td>
</tr>
<tr>
<td>2. Develop an inventory of behaviors. (preventative/treatment)</td>
<td></td>
</tr>
<tr>
<td>3. Rate behaviors in terms of importance. (clear causal link to health issue and frequency)</td>
<td>Rate factors in terms of relationship to health, behavior and incidence.</td>
</tr>
<tr>
<td>4. Rate factors in terms of their change potential.</td>
<td></td>
</tr>
<tr>
<td>5. Choose targets for the intervention program by setting up a rating table (figure 1.7), and state behavioral and environmental objectives.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1.6 Steps for Behavioural and Environmental Diagnosis
Quadrant 1 identifies the highest priority targets for the intervention program. Quadrant 2 deserves attention for the development and evaluation of innovative approaches. Quadrant 3, although less important, should also be considered only when a subjective rating of importance may lead to support of the individual or community in dealing with other important factors.

iv) Phase 4 - Educational and Organizational Diagnosis
In this part of the PRECEDE model the many factors which have been identified through research as influencing a specific health behaviour are compiled and grouped under either an educational or organizational orientation. The factors are divided into three categories: predisposing, enabling, and reinforcing factors. Predisposing factors include a person's knowledge, attitudes, beliefs, values and perceptions. Enabling factors include any skills, resources or barriers that either make possible or inhibit the desired change. For example specific regulations or facility accessibility may enable behavioural change. Reinforcing factors are the rewards and feedback received after adopting a new behaviour. These factors either encourage or discourage practice of a new behaviour or participation in a health promotion program. For example, feedback from, or attitudes of peers, parents or employers affect continued practice of a behavior (figure 1.8).
Figure 1.8 Phases 4 and 5 of the PRECEDE Model which addresses the strategies and resources required to influence the predisposing, reinforcing and enabling factors influencing or supporting behavioural and environmental changes (Green and Kreuter, 1991, p. 30).
Once all of the predisposing, enabling and reinforcing factors have been identified through either informal methods (interviews, discussions, questionnaires, focus groups, etc.) or by more formal methods (review of literature, surveys, etc.) the factors to be targeted in the intervention program are listed in priority based on their relative importance and changeability. Learning and resource objectives are then set. This phase and the next greatly help in identifying the many factors that must be considered in the actual design of the health promotion intervention program.

v) Phase 5 - Administrative and Policy Diagnosis

In this phase, the actual health promotion program is developed, including the method, strategy and staff selection, for intervention into its specific setting. Health education components of the intervention program, the policies, regulations and organization are considered (figure 1.8). The administrative capabilities and policy details aid in the process of identifying possible limitations or barriers to implementation in the specific setting. Budget and political forces are assessed. Health promotion programs are typically implemented into community, work site, school or health care settings, each with their own set of policies, rules and regulations. This phase marks the transition from PRECEDE to PROCEED.

vi) Phase 6 - Implementation

After accounting for the factors in phase 5 which either facilitate or hinder the implementation process, the program is initiated. Evaluation and feedback begin immediately. Training, supervision and personnel options within the program should be included in the program. The following characteristics of
successful health promotion programs have been identified and are associated with higher sustainability.

A successful health promotion program has:
- a good plan
- adequate budget
- good organization, policy and support
- good training, supervision and monitoring
- long term goals set
- a leader with a sense of humor
- experienced staff, and is
- sensitive to people's needs
- and is flexible (Green and Kreuter, 1991).

vii) Phase 7-9 - Evaluation
Phases 7 through 9 are the evaluation components of the model and are important parts of the continuous planning process. The objectives set out during PRECEDE form the criteria for evaluation. Evaluation can guide the smooth running of the intervention program (process evaluation), it can show if the program actually reached and served the target population (impact evaluation), and finally, it determines if the intervention achieved the improvements intended in health outcomes (outcome evaluation).

Phase 7. Process Evaluation:
This phase is important in helping to guide program decisions. It should be a continuous process throughout the planning, implementation and actual running of the implementation program. It will help identify problems with the program.
so they can be rectified. Problems identified and corrected immediately will most likely have a positive impact on the adherence rate to the program. Suggested methods for evaluating the process are: surveys, audits, counts of services, reports, book keeping, peer review and other external observations.

Phase 8. Impact Evaluation:
Impact evaluation measures the short term or immediate outcomes of the health promotion program. Target behaviors and environmental factors identified in phase 3 along with their associated predisposing, enabling, and reinforcing factors outlined in phase 4 are assessed for change.

Phase 9. Outcome Evaluation:
The last phase of the PRECEDE PROCEED model evaluates the outcomes resulting from the intervention program. In other words, it addresses the more long-term goal of improvements in quality of life and/or decreases in suffering from health problems for which the health promotion intervention was undertaken in the first place (phase 1). Changes in the 5 "D's" (death, disease, disability, discomfort, dissatisfaction) along with social and quality of life indicators mentioned in phase 1 and 2 are examples of the measures used to evaluate this component.

The PRECEDE PROCEED model emphasizes the multiple determinants of health and quality of life. The framework is based on many disciplines, such as epidemiology, social, behavioural, and educational sciences and health administration to accommodate this characteristic. Using the model is an effective way of bringing the disciplines together and organizing the information to gain an understanding of quality of life and how to plan to improve it. The
flexibility to different settings, including schools, makes the PRECEDE PROCEED model a valuable tool for planning most any health promotion program.

1.8 Adherence to Exercise

Physical activity has been identified as having a positive impact on bone density thus adherence to a regular exercise program is necessary to gain the potential benefits of physical activity. Drop-out rates tend to be very high, approximately 50%, in the first six months for individuals starting an exercise program (Dishman, 1988). This high drop-out rate makes investigation into the factors affecting exercise program adherence advantageous in that they could be considered in the planning of an exercise program and hopefully facilitate higher adherence rates. Predisposing, enabling, and reinforcing factors, as identified in the PRECEDE PROCEED model, affecting exercise program compliance are reviewed here.

Predisposing Factors:

Some of the predisposing factors, which include people's beliefs, values and attitudes, tend to remain relatively constant over time. New knowledge, however, may have some impact on these factors, especially during adolescence when beliefs, values and attitudes are not yet as ingrained as in adulthood. For example, a school-based health education program about AIDS, which used the PRECEDE model, found significant differences between pre and post-test scores for knowledge and some attitudes and beliefs (Alteneder et al., 1992). An increase in knowledge does not always cause change in behaviour and it is not enough to cause behavioural change in most cases (Brouchard, 1991). Increased knowledge, however, may serve as a motivational factor and was a necessary
component for a conscious health action to occur (Dishman, 1988; Green and Kreuter, 1991; Naylor, 1992).

Knowledge may be more crucial or beneficial in situations where the knowledge level is low. More knowledge (Brouchard, 1991; Dishman, 1991) about the benefits of regular exercise, of particular interest to the adolescent female, may be a key force behind adolescent participation in regular physical activity. The Health Promotion Survey (Health and Welfare Canada, 1993) indicated that among adults knowledge of health risks was the main factor, stated by the majority of respondents (67%), which helped them to change health habits for the better, however, it is not a good predictor for health behaviour change. Education programs which included lessons on goal setting made the educational component more valuable (Dishman, 1991). Feelings of vigor, well-being and enjoyment from physical activity are probably more important to current exercise habits of adolescents (Dishman 1991 and 1988).

A study of middle-school students found that beliefs about the benefits of regular exercise and attitudes towards physical education significantly contributed to the intent to exercise (Ferguson et al., 1989). Those who held stronger beliefs that exercise provides health benefits had higher adherence patterns (Dishman, 1991; Health and Welfare Canada, 1993; Parcel et al., 1989). Personal incentive or motivation to exercise, energy or willpower, and perceptions of sense of self were also significant predictors of adolescent exercise behavior (Health and Welfare Canada, 1993; Johnson et al., 1990; Tappe et al., 1990).
The Health Belief model explains and predicts health related behaviours based on a combination of beliefs held (Green and Kreuter, 1991). For health-directed behaviour to occur the following four beliefs must be held. People must:

1. believe their health could be in jeopardy, or that they are personally susceptible to a certain health problem,
2. perceive the potential seriousness of the condition or consequences of the health threat, or in the case of screening health behaviour, believe that they could have the serious condition without the symptoms,
3. perceive that the benefits from the recommended program or behaviour outweigh the costs, and that the benefits are reasonably attainable, and
4. have a "cue to act" or a precipitating force that makes them feel that they need to act on their health.

Sometimes knowing or perceiving the health problem to be serious arouses fear which can either motivate an individual to act (i.e., fight the health problem) or make them feel helpless (i.e., ignore, avoid, deny or flee the health problem). In a recent study, adherence to an exercise program by those with hypercholesterolemia was positively associated with the perceived seriousness of the problem, expected benefits from the program and subsided feelings of helplessness (Lynch, 1992). However, fear arousal, as a method of health education, must be regulated to arouse enough fear to motivate, but not so much as to immobilize, cause denial and suppression of the knowledge.
Self efficacy, feelings of control as opposed to helplessness, was a personal factor predisposing adherence to exercise (Dishman, 1991; Green and Kreuter, 1991; Health and Welfare Canada, 1993; Tappe et al., 1990). If people felt that they had some control over their health, and/or could do the behaviour necessary to improve health, they were more likely to act and make positive behaviour changes (Dishman, 1991). Self efficacy incorporates social learning theory with the understanding that people are acted upon by, and act upon, their environment (Green and Kreuter, 1991). The Canada Fitness Survey (Stephens and Craig, 1990) found that about one third of Canadians believed that they had little control over their level of regular exercise. Increased knowledge may increase self-efficacy in this situation (Parcel et al., 1989).

Personal feelings about body weight and image, smoking behavior, previous activity experience, skills, attitudes and perceived time also affected participant adherence to exercise programs, especially for adolescents (Dishman, 1991; Health and Welfare Canada, 1993; Naylor, 1992; Wankel, 1985a). Sixty-one percent of 10-14 year old females surveyed in the Canada Fitness Survey felt positive about vigorous exercise but 38% felt that time pressure from school was a barrier to regular physical activity participation (Stephens and Craig, 1990). Perceived or actual lack of time was one of the most common barriers to regular exercise documented (Dishman, 1991; Health and Welfare Canada, 1993; Johnson et al., 1990; Naylor, 1992; Tappe et al., 1989; Wankel, 1985b). This barrier corresponds with the third assumption of the Health Belief model indicating that the time cost for regular exercise outweighed the possible health benefits to be gained. Shephard (1985) concluded that correcting the perception of "lack of time" and/or by teaching people how to budget their time, would do
more to increase exercise adherence and participation than providing information, facilities, equipment, or even more free time.

**Enabling Factors:**

Enabling factors specific to exercise program adherence and compliance were mostly related to program characteristics and the resources needed (Dishman, 1988; Health and Welfare Canada, 1993; Naylor, 1992; Robinson and Rogers, 1994). Leadership has been singled out as one of the most important variables affecting compliance with exercise programs (Dishman, 1988; Wankel, 1985b). Good leaders are able to motivate and gear programs to meet individual needs. Eriksen et al. (1988) also emphasized the importance of this characteristic in their model of principles for effective program planning.

Although there were mixed conclusions about the effects of exercise intensity on compliance, most researchers in this area stated that success in program adherence was facilitated by exercise programs which involved moderate intensity, of not longer than one hour duration per session, gradual progressions, sufficient rest between sessions, flexibility, safety, and variety in the type of exercises (Dishman, 1991 and 1988; Naylor, 1992; Nicholas et al., 1993; Wankel, 1985a and 1985b). Inconvenient facilities, poor weather and lack of skills needed to exercise were mentioned most frequently by adolescents as barriers to exercise (Health and Welfare Canada, 1993; Tappe et al., 1989; Wankel, 1985a and 1985b). However, it was difficult to conclude if these were true barriers or if they just reflected lack of motivation, interest or energy to participate (Dishman, 1991). Inclusion of skills teaching in an intervention program was mentioned as having potential to increase feelings of competence and self efficacy which in turn could increase adherence (Green and Kreuter,
1991). Some of these factors may also serve as reinforcing factors discussed in the next section.

Many intervention programs have used cognitive and/or behavioral strategies to try to increase program adherence. It is not the intent of this review to describe them all but to briefly review their overall impact. Reinforcement, stimulus control, psychological models (e.g., Skinner, Fishbein and Ajzen), relapse prevention, transtheoretical staging, decision making, goal setting, written agreements, contracts, self-monitoring, and structured social support are some examples of strategies used (Dishman, 1991; Naylor, 1992; Shephard, 1985; Wankel, 1985a; Robinson and Rogers, 1994). Studies which compared groups involved in behavioural strategies to control groups generally showed higher adherence rates for those who used a strategy (Belisle et al., 1987; Dishman 1991 and 1988; Naylor, 1992; Wankel, 1985a). Studies which investigated the differences in impact of two or more different strategies on exercise adherence failed to show significant results (Dishman, 1991; Keefe and Blumenthal, 1980; Naylor, 1992; Noland, 1989). No one intervention was consistently and significantly more effective than others and interventions had little impact on already regular exercisers (Noland, 1989). However, strategies which included reinforcement, relapse prevention (self-regulatory skills) and structured social support tended to show more positive results than self-monitored programs alone (Belisle et al., 1987; Dishman 1991 and 1989; Eriksen et al., 1988; Noland, 1989).

**Reinforcing Factors:**

Social support, influence and feedback from significant others acted as both enabling and reinforcing factors impacting long-term exercise program
adherence (Dishman, 1991; Dwyer et al., 1991; Green and Kreuter, 1991; Nicholas et al., 1993; Robinson and Rogers, 1994). The factors which initially motivated someone to participate in a program were quite different than those needed to foster long-term participation (Wankel, 1985b). Knowledge of health risks and benefits and tangible incentives were cues to act, but enjoyment, social aspects, continued reinforcement, and rewards from the exercise itself, such as increased sense of well-being, fitness or attractiveness became more important for exercise continuation (Dishman, 1991; Health and Welfare Canada, 1993; Nicholas et al., 1993; Shephard, 1985). It is difficult, however, for individuals to distinguish between external and internal reinforcing factors and their importance to exercise adherence.

Little research has been done specifically on adolescent adherence to exercise and there is lack of consistent measurement techniques and long-term follow-up studies (Robinson and Rogers, 1994) but many of the factors associated with adult compliance are applicable. Adolescents are at a different stage of understanding health issues and personal responsibility for health, and they tend to view the threats of chronic disease as more remote, therefore, many different factors and strategies should be considered and applied when developing and implementing health promotion programs for them (Dishman, 1988; Robinson and Rogers, 1994).

The following quote from Wankel's book (1985a, p. 278) describes the ideal exercise intervention program.

Martin and Dubbert (1982) after an extensive review of the adherence literature recommended the development of an optimum treatment package for enhancing exercise adherence. In this regard they state:
...the optimal treatment package should probably include a very convenient location (e.g. neighborhood-based programs), group-based, lower intensity exercise with enthusiastic participant therapists, ample modeling, feedback and social reinforcement, flexible, participant influenced exercise goal setting, and extensive family/social involvement. The program should also be tailored to individual needs, for example, personal health goals/limitations, body composition, skill level, need for social approval versus independent pursuit of goals, and desire for variety or competition versus camaraderie (Oldridge, 1977; 1982). Choice, either perceived or actual, appears to be important to adherence to exercise (Thompson and Wankel, 1980) as well as other behaviors (Kirschenbaum, Tomarken and Ordman, 1982). In respect to the overly competitive individual (e.g. Type A), we recommend that very highly competitive activities be allowed only in addition to a more relaxed, enjoyable fitness training/maintenance program (p. 1013).

1.9 School-Based Health Promotion Programs

Much attention has been given to implementing successful health promotion programs in the school environment because the school environment is such an excellent setting for reaching the majority of children and adolescents (Green and Kreuter, 1991; Simons-Morton et al., 1988). In addition, school age is an excellent time to intervene with health education and promotion programs because this is when lifestyle habits are being formed from the influence of significant others such as teachers, peers, and parents (Dishman, 1988; Ferguson et al., 1989). The school system has one of the strictest set of policies and regulations, which makes it difficult to start new and innovative programs (Green and Kreuter, 1991).

Studies have been conducted investigating the effects of health education programs in school settings, offering suggestions for dealing with the organizational and policy limitations, and for facilitating organizational change (Dopp, 1986; Downey et al., 1987; Floyd and Lawson, 1992; Hillman et al., 1985; Parcel et al., 1989; Simons-Morton et al., 1988). Significant differences in
knowledge, attitudes, and locus of control have resulted from school-based health education programs, however, results of both positive change and no change in health related practices have been observed (Hillman et al., 1985; Parcel et al., 1989; Simons-Morton et al., 1988). The positive results of school health education programs illustrates the that they can influence health outcomes in a cost effective manner if they are planned well for each situation, and are sustained for more than one year (Green and Kreuter, 1991).

Floyd and Lawson (1992) outlined a four-step model to ensure a school's ability and willingness to support and implement a health education or health promotion program. The initial step involved assessing the school's resources and priorities, and the personnel's attitudes and beliefs about the program. Step two (organizing) involved dividing tasks, marketing the program and setting up a framework that enhanced communication, sense of ownership and motivation. Step three (implementation) involved deciding on what strategy would best educate and challenge participants to take more responsibility for their own health. The last step, step four (evaluation) ensured continuous feedback and modifications to encourage long-term program commitment and success.

The steps outlined by Floyd and Lawson (1992) correspond to the components of the PROCEED model. They also emphasized the PRECEDE steps, which applied to those who would implement the program, such as identification of predisposing, enabling and reinforcing factors influencing school personnel's involvement and commitment to the program. Commitment from teachers and staff has been highlighted as a key element for influencing schools to adopt programs, and for program success in changing health behavior. The importance of a team approach between students, teachers, administration, and
community to ensure a common goal is also emphasized (Floyd and Lawson, 1992; Green and Kreuter, 1991; Parcel et al., 1989). Change in a school's organizational structure to accommodate new health education programs, whether large or small, was outlined as a sequential pattern involving institutional commitment, changes in policies, alterations in roles of staff, and changes in student's learning activities (Green and Kreuter, 1991; Parcel et al., 1989).
Chapter 2. Statement of the Problem

Based on the review of literature, osteoporosis prevention beginning during adolescence may prove to be very beneficial. No long-term (more than 12 months) intervention studies have been published with adolescent subjects investigating the effects of weight-training exercise and calcium supplementation on bone mineral and bone size, taking into consideration the bone remodeling transient. The related studies which have been completed investigated only one of these variables and/or were limited by the duration of study or other methodological factors. Therefore, it was necessary to investigate this issue to determine whether or not such an intervention program would be effective in augmenting bone mineral and size during adolescence.

2.1 Objectives

The objectives of this study were:

1. To determine the effects of an 18-month progressive weight-training and/or calcium-supplementation program on bone mineral content of healthy adolescent females.

2. To determine the effects of an 18-month progressive weight-training and/or calcium-supplementation program on bone mineral density of healthy adolescent females.

3. To determine the effects of an 18-month progressive weight-training and/or calcium-supplementation program on bone size and skeletal area of healthy adolescent females.

4. To identify variables affecting adolescent compliance with the intervention program.

5. To use a health promotion planning and evaluation model (PRECEDE PROCEED) to design the school-based intervention program.
6. To investigate the existence and effects of a bone remodeling transient on bone mineral content and density after introduction of a weight-training and calcium-supplementation program.

2.2 General Hypothesis

Increases in bone mineral content, density, skeletal area and bone size will be greater in those subjects who participated in the progressive weight-training and calcium-supplementation program than those in the non-exercising and placebo control groups.
Chapter 3. Methodology

3.1 Study Design

This study was a 2x2 factorial, quasi-experimental, controlled intervention involving two independent variables, weight training and calcium intake. School-aged subjects were divided into a control or experimental group based on the school they attended which was randomly assigned as a control or experimental school. Subjects were screened for factors known to affect bone mass. A matching procedure, to match experimental and control subjects closely for body weight, maturation and height was used to form blocks of four subjects. The matched blocks were used to decrease variance between subjects and groups. One pair in each block was then randomly assigned a calcium supplement and the other pair received a placebo (table 3.1). All subjects were pre-tested. The experimental group participated in a progressive weight-training program. The non weight-training control group maintained their current lifestyle. All subjects were measured again at six months and at eighteen months. The main dependent variables were bone mineral content, bone mineral density, and bone size (skeletal area).

<table>
<thead>
<tr>
<th></th>
<th>Weight-training Experimental Group</th>
<th>Non Weight-training Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>weight training plus calcium</td>
<td>no weight training plus calcium</td>
</tr>
<tr>
<td>Placebo</td>
<td>weight training plus placebo</td>
<td>no weight training plus placebo</td>
</tr>
</tbody>
</table>

Table 3.1 Treatment and Control Groups

The University of British Columbia Behavioral Sciences Screening Committee for Research Involving Human Subjects approved the research study (Appendix A).
3.2 Subject and School Recruitment

Principals and physical education teachers in public secondary schools in North and West Vancouver, B. C. were asked if they would be interested in participating in and supporting the study. The schools were generally similar in Physical Education curriculum, weight-training facilities, and socioeconomic status/location (all on the North Shore). School-board approval was given to the schools to participate (Appendix A). Four volunteering schools, out of the seven approached and investigated for similarity in curriculum and facilities, were chosen for the study. Two schools were randomly chosen as experimental schools and two as control schools. In late August 1994, information packages, including the initial screening questionnaire and informed consent, were sent to all female students (grades 8 through 11), and their parents, attending the four schools (Appendix B). During the first two weeks of school in September, interested subjects and their parents were invited to an information meeting held at their school. Those interested in volunteering to participate in the study returned the informed consent and screening questionnaire. At this point potential subjects did not know if they would be in the experimental group (exercise and/or calcium supplementation) or the control group.

3.3 Subject Selection

Subject selection was based on the following criteria. Those not meeting the criteria were excluded from the study. Subjects must have:

1. returned the informed consent (signed) and the initial screening questionnaire,
2. planned to live in the area for the study duration,
3. led a relatively sedentary lifestyle except for school physical education classes and intramural sports,
4. been a nonsmoker,
5. never taken oral contraceptives,
6. not had any major illnesses to exclude their participation in physical activity,
7. completed and returned the self-rated Tanner Staging maturational questionnaire for breast and pubic hair development (Appendix C) (Tanner, 1955; Matsudo and Matsudo, 1993),
8. not been regular coffee and/or cola drinkers (more than 3 cups per day),
9. been free of any chronic or genetic illnesses or any medical conditions affecting bone or requiring medication,
10. been in the healthy body mass index (BMI) zone of 18-27 kg/m² (Fitness and Amateur Sport, 1996),
11. no known eating disorder and were not participating in dieting (purposefully restricting calories) and
12. not been involved in strenuous, long-term exercise training throughout their childhood or adolescence. Strenuous training was considered training at least at a provincial competitive level for more than two years continuously in any weight-bearing sport, especially in gymnastics, figure skating, dance or weight training.

A lifestyle questionnaire determined the status of many of the above mentioned criteria (Appendix D).
Based on the screening 108 subjects were admitted to the study (66 subjects from Handsworth school, 19 subjects from Windsor school, 16 subjects from Sentinel school, and 7 subjects from Argyle school). Handsworth and Sentinel had been randomly chosen as the weight-training schools but for logistical purposes of implementing the training program Handsworth became the only experimental school as over half the subjects were there. Fifty-four subjects at Handsworth were randomly chosen as weight-training subjects and the remaining subjects were nonexercisers. Using a computerized program each exercise subject was matched to a non-exercise subject based on the following weighted factors, in order of highest to lowest: body weight, maturational age (months past menarche), and height (Appendix E). The weighting factors were four, two and one respectively, with body weight receiving the highest weighting because of its strong positive relationship to bone mineral, as indicated in the review of literature. A computer program matched the subjects so the least overall difference existed between the subjects on the three variables.

Each pair was then matched again to another pair based on the same variables (weight, maturational age, height) to form a block of four subjects. One pair in each set of two pairs was randomly assigned to take the calcium supplement of 1000 mg/d and thus the other pair received the placebo.

3.4 Initial Measurements

The following measurements (further detailed in Appendix F) were taken during November and December 1994 before the intervention program began:
Bone Mineral Content, Density and Skeletal Area:

The following bone sites were measured for bone mineral content and density: whole body, lumbar spine (L2-L4), and proximal femur (trochanter, femoral neck). Skeletal area is measured first by DXA by counting bone-containing pixels, then bone mineral density is calculated by dividing bone mineral content by area. The subjects signed a hospital waiver ensuring that they were not pregnant (Appendix G). All scans were completed by the same two technologists who were registered Nuclear Medicine Technologists. These measurements were taken at St. Paul's Hospital, Nuclear Medicine Department, using a Norland XR-26 Mark II/HS Dual-Energy X-Ray Absorptiometer and followed the procedures as outlined in the XR Series Densitometer Operators Guide (Norland, 1992). The machine was calibrated daily against a spinal phantom. A speed of 90 mm/s, resolution of 4.5 x 9.0 mm, and scan width of 62.1 cm were used for the whole-body scan. This speed, which was slower than the standard speed used for clinical scans of this site, was used to achieve greater precision. The standard speed of 60 mm/s, resolution of 1.5 x 1.5 mm, and a scan width of 12 cm was used for the lumbar spine. The standard speed of 45 mm/s, resolution of 1.0 x 1.0 mm, and a scan width of 9 cm was used for the proximal femur scan. The standard speeds were used for the spine and hip scans as there was little effect on precision. Appendix H shows a printout of a Norland densitometer DXA scan. The operator's guide states that accuracy for the scans is within 1% of the industry standard and for whole-body scans, done on the high precision speed, precision was 0.6%. For lumbar spine L2-L4 precision for bone mineral content, bone mineral density and area were 1.5%, 1.0%, 1.0% respectively. For the proximal femur scan femoral neck precision was 1.2%, 1.7% and 1.1%, and trochanter precision was 1.8%, 3.7% and 2.9% for bone mineral density, bone mineral content and area respectively (Norland,
Two consecutive whole-body scans on each of ten, young-adult females of similar size to the study participants were completed to check for precision and reliability. Due to ethical reasons regarding radiation, additional scans could not be completed on the subjects to test reliability, which is why the young-adult females were used. Complete subject repositioning was done between scans. Correlations between repeat measures, for the variables measured through whole-body scans (bone mineral content, bone mineral density, lean mass, fat mass, area, and percent fat) were above 0.98 except for area which was 0.96. Again due to ethical reasons, scans of the proximal femur and spine could not be completed on these adults to check reliability and precision because they are sites used for diagnostic purposes.

For the whole-body, scan subjects were positioned in the center of the bed with the tops of their heads at the edge of the scan border which was indicated with tape around the edge of the bed surface. The neck was held straight with chin up so subjects looked up at the ceiling. A light tug down was given on each arm and leg to ensure the limbs were straight. Hands were placed palms down, fingers together with the small finger just inside the scan border. The feet were positioned with heels apart, toes pointing inwards with one inch between the feet and were taped in that position so the subjects could relax yet maintain the standard position. For the lumbar scan a large block was placed under the subjects' knees so their hips and knees were at right angles and their backs were flat on the bed (figure 3.1). For the proximal femur scan a hard foam board 43.5 cm long was placed between the feet. Their upper thighs were put in a brace and secured with velcro straps. The straps were tightened to internally rotate the hip to a standard strap number position of seven (figure 3.2).
Figure 3.1 Lumbar Spine (L2-L4) DXA Scan Position

Figure 3.2 Proximal Femur DXA Scan Position
**Anthropometry:**

The following anthropometric variables were measured: height, weight, circumferences (waist, hip, forearm, calf, upper arm, mid thigh), skinfolds (biceps, triceps, subscapular, suprailliac, front thigh, medial calf), and bone breadths (biacromial, biepicondylar, radial ulnar, bicristal, bicondylar, ankle). Body mass index (BMI) was also calculated.

The measurement techniques used for the above measures were those of the Canadian Standardized Test of Fitness (Fitness and Amateur Sport, 1986) and standardized methods documented elsewhere (Docherty, 1995; Malina and Bouchard, 1991; Willis, 1989; Yuhasz, 1987). Harpenden calipers (British Indicators, Ltd., St. Albans, Herts., U. K.) were used for the skinfold measurements. These measurements were taken at the hospital when subjects came to have their bone mineral measures done. The author took all measurements on all subjects.

**Strength:**

The following exercises were used in the measurement of strength: biceps curl, shoulder press, bench press, hamstring curl, quadriceps extension, and seated row. Strength was measured, by the author, on these exercises using the 1 repetition maximum (1RM) procedure on Universal multi-station weight-training equipment available at the subjects' school. The same basic instructions were given to the subjects before each test. Subjects participated in a warm-up then had a trial at each of the strength-testing stations using very low weights to ensure proper technique. During the 1RM tests weight was added a plate at a time until subjects reached their maximum lift (within three lifts). The last weight successfully lifted was recorded as their 1RM.
Dietary Information:
To acquire dietary information, especially dietary calcium intake, three-day food records and food-frequency questionnaires were used (Bergman et al., 1990; Livingstone et al., 1992; Rockett and Colditz, 1997; Schoeller, 1990). Each subject was given a three-day food record (Appendix I) while at her hospital testing session and was instructed on how to complete it. Written instructions were also attached which included pictures for reference of serving sizes. A calcium food-frequency questionnaire (Appendix J) was also completed at this time with the author asking each of the questions and recording the answers.

3.5 Intervention Program Planning - PRECEDE PROCEED Model
A comprehensive, evidence-based health promotion planning and evaluation model was used to maximize the potential for a successful intervention program in the school setting. Adherence to the experimental exercise and calcium-supplementation program was necessary to attain the data needed to address the research question at hand. The success, wide use of and scientific basis of the PRECEDE PROCEED model, and recommendations for its use were the rationale for applying it to the specific health issue addressed in this study. The model was applied to help plan the 18-month school-based weight-training and calcium-supplementation program for adolescent females.

Each phase of the PRECEDE model (phases 1-6) was followed and specifically applied to the development of a logic model and intervention strategy for osteoporosis prevention through increasing adolescent bone mass and size. Indicated below is an outline of Appendix K which details each phase of the application of PRECEDE. The methodology sections outline the evaluation methods employed in the remaining PROCEED phases.
Appendix K-1: Social Diagnosis:
Phase 1 - Discussions with researchers, doctors, and school teachers as well as a thorough review of the literature aided in identifying the health and quality of life concerns.

Appendix K-2: Epidemiological Diagnosis:
Phase 2 - The epidemiological data and contributing risk factors related to osteoporosis and low bone mass in adolescent girls were outlined and the program goal and health objectives were stated.

Appendix K-3: Behavioral and Environmental Diagnosis:
Phase 3 - The 5 steps in this phase were applied to osteoporosis and low bone mass to identify all factors affecting bone mass and then to identify the top priority factors to address in the program.

Appendix K-4: Educational and Organizational Diagnosis:
Phase 4 - The predisposing, enabling and reinforcing factors associated with osteoporosis prevention and peak bone mass were identified, then the main behavioural and environmental determinants were rated for their importance and changeability.

Appendix K-5: Administrative and Policy Diagnosis:
Phase 5 - The resources needed, the resources available and the barriers to the school-based intervention program were identified.
Appendix K-6 and L: Implementation:

Phase 6 - The intervention program details, considering the outcomes of the previous steps, were outlined.

Phases 7-9 - Process, Impact and Outcome Evaluation, together with the implementation (phase 6) makes up the PROCEED part of the model. Peer reviews from the physical education teachers, school representatives, parents and the student subjects themselves were the most valuable method of process evaluation throughout the program. Frequent verbal communication with all parties involved allowed for program problems, concerns, and suggestions to be raised and dealt with immediately to ensure the successful continuation and development of the program. A questionnaire completed at the end of the study by participants evaluated the program's process (Appendix M).

Lifestyle questionnaires, three-day dietary records, attendance log books, and the program questionnaire were the methods used for evaluating behaviour change (impact evaluation) for this osteoporosis prevention program. Outcome evaluation included strength and bone mineral density, content and size measures of the subjects. Incidence rates of osteoporosis or osteoporotic fractures arising in the subjects who participated in the program will not be known for many years. However, from the above measures of outcome evaluation, it may be possible to predict the health and quality-of-life outcomes. Some quality-of-life improvements might result in the short-term framework of this study as a direct consequence of the behaviour changes and improved strength levels.
The model was designed to lead the health promotion professional to the cause of the health problem of interest. Related factors of the health issue are, therefore, usually phrased in terms of implying a cause of the problem, e.g. the behavioural factor, "sedentary lifestyle," may be a cause of low bone mineral content and density leading to osteoporosis. Recent emphasis in health promotion efforts, however, reflected a more positive approach in which factors were phrased in terms of what needed to happen to eliminate the health problem. Taking the behavioural factor example from above, "sedentary lifestyle," is then stated as "regular exercise." This can help increase bone mineral content and prevent osteoporosis. Therefore, for the purpose of this research effort, the factors associated with osteoporosis prevention and increasing adolescent girls' bone mineral content were stated in the positive sense (e.g., factors that could prevent low bone mineral and osteoporosis).

3.6 Intervention Program

**Weight-Training Exercise Program:**

During early December 1994 all experimental subjects participated in an educational session to learn i) how to use the weight equipment properly and safely, ii) correct exercise technique, iii) how to increase the weight load progressively, and iv) how to fill out their record sheets. The subjects completed a two-week, warm-up weight-lifting program prior to Christmas holidays to become familiar with the exercises and weight equipment. This program involved completion of three sets of 8-12 repetitions of a series of ten exercises, between 65-75% of their 1RM, three times per week. The ten exercises chosen were basic weight-training exercises that would stress each of the major muscle groups. The intensity implemented was moderate so subjects would not experience extreme muscle soreness and be discouraged from participating.
January 1, 1995 marked the beginning of the intervention program. The experimental group was involved in an 18-month progressive weight-training program while subjects in the control group were asked to continue with their normal lifestyle. The subjects used the weight room at their school and had free blocks either before, during or after school to complete their workouts. Subjects were supervised in the weight room by either physical education teachers, senior student weight-room supervisors who also had completed a weight room training session, or the research assistant. The weight-training program consisted of two different workouts of ten exercises each using a combination of machine and free weights. The program was based on physiological training principles for strength training (Fox et al., 1989; McArdle et al., 1995) (Appendix L). The program emphasized strength training, as opposed to endurance training, since it facilitates gains in strength and induces more load on the skeleton through muscular contractions, both of which were positively related to bone mineral in previous research as discussed in the review of literature. Subjects were instructed to train three times per week alternating the two workouts, however, only two workouts per week are required to increase strength and was the number of workouts used to calculate compliance. The exercises were chosen in order to stress the major muscle groups and parts of the skeletal system at highest risk for osteoporotic fractures (hip and spine). The weight-training program was set up in five-week cycles to allow for proper progression, muscle recovery and variety:

- **Week 1**  
  easy intensity  
  3 sets of 15 repetitions of each exercise

- **Week 2**  
  moderate intensity  
  3 sets of 8-12 repetitions of each exercise

- **Weeks 3-5**  
  hard intensity  
  3 sets of 5-7 repetitions of each exercise.
Subjects were instructed that their last three repetitions of each set, no matter what week it was, were to be very challenging to complete. When these repetitions became easy to complete they were to increase the weight load so that again the last three repetitions were difficult or not possible to complete. Subjects worked at an intensity between 65-85% of their 1RM.

The training schedule included four active-rest breaks from the weight-training program, which were evenly spaced throughout the 18 months, to allow for recovery, proper progressions and to maintain motivation. Three of the breaks were one week long and one was three weeks long which coincided with subjects' summer vacation. During the summer the school weight room was open three days a week for two hours in the morning so subjects could continue with their training. If subjects could not make this time they had the option of training at a nearby community recreation centre which had the appropriate equipment for the designed training program. If subjects were going out of town for holidays, this was when they took their three-week break. If their time out of town was longer than three weeks and they did not have access to weight-training facilities, subjects were taught alternative exercises to mimic the same weight-room exercises using make-shift weights and subjects' own body weight. Details of the weight-training program are in Appendix L. An attendance sign-in sheet was posted in the weight room and subjects kept a record of each workout completed (Appendix N).

**Calcium Supplementation:**

All subjects (experimental and control) took a daily calcium or placebo supplement. Individual tablets (provided by Apotex Pharmaceuticals, Weston,
Ontario) contained 500 mg of calcium as calcium carbonate or placebo. Subjects were instructed to take two tablets daily, and both at the same time to improve compliance, even though absorption efficiency may have been slightly decreased by taking it all at once. This amount of calcium ensured that each subject was ingesting at least the recommended level of calcium intake according to Canadian standards (Health and Welfare Canada, 1990). Subjects who were taking vitamin supplements with calcium were asked to refrain from taking them for the duration of the study. A check mark was placed on the subjects' calendar-style record sheets for each day the supplements were taken. Left-over tablets and records were collected at the completion of the study to measure compliance. This aspect of the study was conducted in a double-blind manner so the subjects and the researcher did not know who was receiving calcium. Once subjects were in their blocks, one matched pair in each block was randomly assigned a number one label and the other pair a number two label. The supplements from the pharmaceutical company came coded for calcium or placebo and bottles were labeled with a generic label made specifically for the study. For the duration of the study the number one pairs always got one shape of bottle and the number two pairs always got the other shape of bottle. At the end of the study the research supervisor revealed which bottle shape contained calcium.

**Record Keeping:**

Throughout the study all subjects were to keep a record of their menstrual periods (start date and number of days since the start of their previous period) and any physical exercise in addition to their regular physical education classes or weight-training programs. The physical exercise record included date, type of activity, length of activity and a rating of perceived exertion (Appendix O).
These records were collected at the end of the study and also checked periodically during the study to ensure they were being kept, and to note any changes in menstrual regularity and physical activity levels.

**Incentive Program:**

To keep the subjects involved, motivated and complying with the program, an extensive incentive program was developed (Appendix P). This program included such activities as:

- "stars of the month" prizes for weight-training attendance
- motivational information board in the weight room
- study participant T-shirts; T-shirt design contest
- free membership to their school weight-training club
- 1RM strength tests periodically to show improvement
- recognition in the school and community for participating
- prizes throughout the program for compliance
- frequent personal phone calls to subjects
- frequent mail-outs to subjects and their parents with motivational comments, participation thanks, upcoming events etc.
- socials throughout the study (all subjects together) e.g. dessert meeting, movie night, with refreshments and draw prizes
- printout of bone mineral results and nutritional analysis
- final study celebration with prize grab bags

### 3.7 Six-Month Measurements

At the six-month mark of the study all the measurements taken during the pretest were repeated. The lifestyle questionnaire used in subject screening was also completed again to check if any significant changes regarding the original
screening criteria had occurred. The main purpose of this measurement session was so the remodeling transient in bone could be accounted for. It was also useful in checking compliance with the program through the subjects' records and personal interviews with them.

The same two densitometry technologists completed the bone scans and the author completed all the other anthropometric measurements and the food-frequency questionnaire and subjects also completed the lifestyle questionnaire. The compare screen option on the densitometer software was used to ensure that the same bone area as in the initial scan was being analyzed on each subject.

3.8 Final Measurements

All the measurements taken during the pretest and six-month point, including the lifestyle and self-rated maturation questionnaires were taken again at the end of the 18-month study. Again the author completed all anthropometric measurements and the food-frequency questionnaire and one of the original technologists completed all the bone scans. Subjects completed three-day food diaries and the lifestyle questionnaire as well as a questionnaire about the program and factors affecting compliance (Appendix M).

3.9 Analysis

ANOVA was carried out to determine if any of the groups differed significantly, or if drop outs differed from participants, at baseline on any of the dependent or matching variables. Compliance with the program and attrition were noted. Pre to post changes in strength (1RM scores) were assessed by ANOVA to further confirm compliance with the program. Comparisons of all bone mineral measures were made between exercise and control groups, and between pretest,
six-month test, and post-test scores. ANCOVA, with blocking, and using weight change as the covariate, was completed on all subjects completing the study regardless of their compliance, to measure the intent to treat. Considering compliance, maturation and matching variables, subject sets were modified to determine the intervention's effects on bone if subjects did exercise and did take calcium supplements. How these subject sets were formed is explained in the results section. Repeated measures ANCOVA, with covariates of weight or maturation, was used to determine significant changes between groups across time. ANCOVA, using weight change as the covariate, was also completed to determine the main effects of calcium and exercise, and if there were significant interactions between these two independent variables.

Bone mineral apparent density (BMAD) (Carter et al., 1992; Katzman et al., 1991), an estimated volumetric density, was calculated from the DXA measurements to account for the inherent size artifact during growth to aid interpretation of the bone density changes at the femoral neck and lumbar spine. The following equations were used to calculate BMAD:

a) femoral neck (Katzman et al., 1991):
\[
\text{density} = \frac{\text{mineral content}}{\text{volume}}
\]

estimated true volume = projected area \times \left(\frac{\text{projected area}}{\text{length}}\right)

where:
length = 1.5 cm (standard used from DXA scans)
projected area = bone mineral content (g)/areal bone mineral density (g/cm²)
therefore:
BMAD (g/cm³) = \frac{\text{BMC}}{\text{estimated volume}}

or BMC (g)/projected area \times \left(\frac{\text{projected area}}{1.5}\right)
b) lumbar spine (Carter et al., 1992)

density = mineral content/volume

estimated volume = projected area \times (projected area)^{0.5}

where:

projected area = bone mineral content (g)/areal bone mineral density (g/cm²)

therefore:

\text{BMAD (g/cm}^3\text{)} = \frac{\text{BMC}}{\text{estimated volume}}

or \text{BMC/Projected area} \times (\text{projected area})^{0.5}

Correlation analysis was used to determine the factors which significantly contributed to the variance in bone mineral changes. Exercise compliance, total calcium intake, maturation, weight change, lean body mass change, and upper and lower body strength changes were the variables tested for significant correlations to bone mineral, skeletal area and size changes. Scatter plots were used to give pictorial representation of some of the relationships between variables. Case studies were also analyzed to compare one subject from each of the four treatment groups, who had low dietary calcium intake, to note trends of the effects of the different interventions on bone mineral change.

Three-day food records were analyzed using the Food Processor II (version 3.14 Enhanced, ESHA Research, 1990) computer program to estimate dietary calcium intake from the Canadian food database. Total calcium intake was calculated by adding dietary intake with supplemented calcium (compliance x 1000 mg). Food-frequency questionnaires were used as verification of food diaries and if a subject did not complete a food diary.
Correlation analysis and ANCOVA were used to determine significant differences in changes in bone mineral measures between groups with high total calcium intake and groups with low calcium intake. Low calcium intake was considered to be 600 mg/d or lower and high calcium intake was considered to be 1200 mg/d or higher which corresponded to the U. S. recommended dietary allowance for calcium in adolescents. The high intake value was chosen because it was the RDA, most previous studies indicated benefits of calcium on bone at or above this value, and balance and threshold values from previous research were slightly above this value. The low intake value was chosen as such because it was well below the NIH recommendations for any age group child to elderly (NIH, 1994).

Calcium retention between 6-18 months, the true intervention period, was also calculated. Total body bone mineral content change between 6-18 months was multiplied by 32.2%, the calcium component of bone mineral (Ellis et al., 1996; Martin et al., 1997), then converted to grams of calcium retained per year, then into milligrams of calcium retained per day. Retention per day was divided by mean total calcium intake and multiplied by 100 to get a percent retention, or retention efficiency.

Bone size changes and skeletal area were determined from breadth and DXA measurements, respectively, and repeated measures ANCOVA were completed to test for significant changes across time and/or between groups across time. ANCOVA was also completed to again test for interaction and main effects of calcium and exercise.
Program questionnaires to track factors affecting compliance were analyzed by ranking the means of the rating of importance score for each factor.

The alpha level to determine significance was set at 0.05 for all statistical procedures except that for any interaction analysis a P value of 0.1 was used as a more conservative approach to better identify interactions (Colton, 1974). The SPSS statistical software package (Release 6.0, 1989-1993, SPSS Inc.) was used for all statistical procedures (Norusis, SPSS Inc., 1993; Schutz, 1989; Stevens, 1990). Repeated measures was chosen so the direction of the changes across the study duration could be observed (Schutz, 1989). ANCOVA was chosen to isolate and assess the contribution of the different factors to the variation or changes in the data and to eliminate some of the chance of type II errors with multiple comparisons (Colton, 1974). Blocking was used to reduce variability amongst subjects and covariates were used to reduce error variability and allow for more power in comparing treatment effects (Kuzma, 1992). Although the hypotheses are stated indicating direction of anticipated change, the analyses completed split the significance level between both possible directions of change to decrease type II errors. Also there was the possibility of changes being opposite than anticipated since effects of such a program, the remodeling transient and interaction of calcium and exercise have not been investigated thoroughly in adolescents.

3.10 Delimitations

The following delimitations set the boundaries for inferences concluded from the study:

- school-based program
- generally healthy adolescent girls
- 18-month program
- weight-training and calcium-supplementation intervention program
- BMAD calculation
- alpha level 0.05.

3.11 Limitations

The following limitations of the study were considered when interpreting data and making conclusions based on the results of the study:

- confounding effects of growth and maturation
- attrition of subjects due to changed lifestyle behaviors and non-compliance with the program
- not a true randomized study
- possibility of a small number of subjects due to the limitations imposed by the school curriculum, facilities and/or demands of the study program
- reliance on self-reported lifestyle questionnaires, maturational assessment, weight-training, physical activity, calcium and dietary records
- possible measurement error
- variance in subject motivation
- variance in compliance to progressive exercise intensity levels
- duration of the study.

3.12 Specific Hypotheses

1. Between months 6-18 of the intervention, subjects participating in the weight-training program will have greater increases in bone mineral content and density, skeletal area and bone size than those in the non-exercise group.
2. Between months 6-18 of the intervention, subjects receiving the calcium supplementation will have greater increases in bone mineral content and density, skeletal area and bone size than those receiving placebo.

3. Over the 18-month program, the effects of weight training and calcium supplementation will interact, and the increases in bone mineral and skeletal area in the calcium-supplemented weight-training group will be greater than those in the calcium-supplemented or weight-training only groups, and control group.

4. Factors relating to program convenience, time commitment and enjoyment will have the greatest impact on program compliance.

5. A bone remodeling transient will be evident between 0-6 months of the intervention in the weight-training and/or calcium-supplementation groups, indicated by greater increases in bone mineral and skeletal area in the calcium-supplemented groups and smaller increases, or decreases, in bone mineral and skeletal area in the weight-training groups.
Chapter 4. Results

The following are results from a series of analyses using four different sets of subjects. Inclusion of subjects in each set was based on certain criteria. Due to drop outs and poor compliance, revised subject-to-group assignments were necessary to determine the effects of the intervention on bone. Subject set 1 included all of the original 108 subjects who started the program. Subject set 2 included all 87 subjects who completed the 18-month study, including all three measurement sessions. Subject set 3 included the 50 subjects who not only completed the study, but also maintained at least 50% compliance with the weight-training and calcium/placebo-supplementation program. Subject set four included 28 subjects from set three, matched post-stratification on maturation and weight, so analysis consistent with the original design of matched blocking could be carried out. Results for each of the different analyses are presented under each subject set heading, with sets 3 and 4 presented together for ease of comparisons. Section 4.3 explains in detail how the revised subject sets were formed.

4.1 Subject Set 1 Results - Subjects Who Started the Study

Baseline Descriptives:

Descriptive statistics, including means and standard deviations, for the entire subject group as well as the four treatment groups at baseline are presented in Table 4.1. Single-factorial ANOVAs indicated no significant differences in the dependent variables and variables used to match subjects (weight, height, maturation) between the four groups initially, indicating that the blocking and matching were successful. The mean age of the subjects was 14.8 ± 1.3 years. Mean weight, height and body mass index were 54.9 ± 9.7 kg, 163.5 ± 6.3 cm and 20.5 ± 3.2 kg/m² respectively.
Table 4.1 Baseline Descriptive Statistics (subject set 1, n=108)(unadjusted means)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group: n</th>
<th>Whole Group</th>
<th>Exercise/Calcium</th>
<th>Exercise/Placebo</th>
<th>No Exercise/Calcium</th>
<th>No Exercise/Placebo</th>
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<tr>
<td></td>
<td>108</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Age (y)</td>
<td>14.8 (1.3)</td>
<td>14.9 (1.3)</td>
<td>15.0 (1.6)</td>
<td>14.8 (1.3)</td>
<td>14.5 (1.1)</td>
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</tr>
<tr>
<td>Weight (kg)</td>
<td>54.9 (9.7)</td>
<td>54.4 (9.1)</td>
<td>53.4 (8.0)</td>
<td>55.6 (10.5)</td>
<td>56.0 (11.1)</td>
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<tr>
<td>Height (cm)</td>
<td>163.5 (6.3)</td>
<td>163.2 (6.8)</td>
<td>165.3 (6.0)</td>
<td>162.7 (5.7)</td>
<td>162.7 (6.9)</td>
<td></td>
</tr>
<tr>
<td>Maturation (mo)*</td>
<td>20.6 (17.9)</td>
<td>20.4 (17.1)</td>
<td>19.6 (16.8)</td>
<td>20.7 (16.9)</td>
<td>21.6 (21.5)</td>
<td></td>
</tr>
<tr>
<td>Breast (stage)</td>
<td>3.8 (0.9)</td>
<td>4.1 (0.7)</td>
<td>3.9 (0.9)</td>
<td>3.8 (0.9)</td>
<td>3.8 (0.9)</td>
<td></td>
</tr>
<tr>
<td>Pubic Hair (stage)</td>
<td>3.8 (1.0)</td>
<td>3.7 (1.1)</td>
<td>4.1 (0.9)</td>
<td>3.9 (1.0)</td>
<td>3.7 (0.9)</td>
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</tr>
<tr>
<td>Body Fat (%)</td>
<td>28.9 (6.3)</td>
<td>27.9 (6.9)</td>
<td>27.8 (5.3)</td>
<td>30.1 (5.8)</td>
<td>29.3 (7.0)</td>
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</tr>
<tr>
<td>Lean Mass (kg)</td>
<td>36.1 (5.1)</td>
<td>36.6 (5.5)</td>
<td>36.2 (4.2)</td>
<td>35.6 (5.3)</td>
<td>36.2 (5.5)</td>
<td></td>
</tr>
<tr>
<td>Dietary Calcium (mg/d)</td>
<td>931 (382)</td>
<td>903 (388)</td>
<td>1006 (442)</td>
<td>868 (399)</td>
<td>927 (331)</td>
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</tr>
<tr>
<td>TBBMD (g/cm²)</td>
<td>0.887 (0.09)</td>
<td>0.884 (0.09)</td>
<td>0.888 (0.08)</td>
<td>0.881 (0.09)</td>
<td>0.896 (0.10)</td>
<td></td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>2.237 (0.32)</td>
<td>2.248 (0.32)</td>
<td>2.255 (0.33)</td>
<td>2.203 (0.34)</td>
<td>2.242 (0.33)</td>
<td></td>
</tr>
<tr>
<td>FNBMD (g/cm²)</td>
<td>0.923 (0.12)</td>
<td>0.930 (0.14)</td>
<td>0.927 (0.11)</td>
<td>0.916 (0.10)</td>
<td>0.918 (0.13)</td>
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<td>Troch. BMD (g/cm²)</td>
<td>0.765 (0.12)</td>
<td>0.777 (0.15)</td>
<td>0.755 (0.10)</td>
<td>0.754 (0.11)</td>
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<td>L2-L4 BMD (g/cm²)</td>
<td>0.932 (0.13)</td>
<td>0.926 (0.15)</td>
<td>0.916 (0.12)</td>
<td>0.932 (0.15)</td>
<td>0.956 (0.11)</td>
<td></td>
</tr>
</tbody>
</table>

* Maturation was measured as months past menarche.

There were no significant differences between groups for any of these variables.

TBBMD=total body bone mineral density.
TBBMC=total body bone mineral content.
FNBMD=femoral neck bone mineral density.
Troch. BMD=trochanter bone mineral density.
L2-L4 BMD=lumbar spine bone mineral density.
**Program Compliance:**

One hundred and eight subjects started the study and nine dropped out within the first six months for the following reasons:

a) moved to a new city (n=1)
b) could not swallow the calcium/placebo tablets (n=1)
c) had no interest in the study to begin with but joined because of parental influence (n=3), or
d) felt the commitment and inconvenience of the program was too much considering their interest level and involvement in other activities (n=4).

Nine more subjects failed to complete the study for the following reasons:

a) moved to a new city (n=1)
b) started using oral contraceptive pills (n=1)
c) other high school activities were of greater priority and program commitment and inconvenience was too much (n=7).

Three subjects did not have the six-month measurement session done because their parents were worried about radiation exposure from the DXA even though the minimal risk was explained to them thoroughly. This left 87 subjects who completed the study. The drop-out subjects were not significantly different on any of the baseline variables than the subjects who completed the study.

**4.2 Subject Set 2 Results - Subjects Who Completed the Study**

**Baseline Descriptives:**

Baseline descriptive information on the 87 subjects who completed the 18-month study is presented in table 4.2. There were no significant differences
Table 4.2 Baseline Descriptive Statistics (subject set 2, n=87) (unadjusted means)

<table>
<thead>
<tr>
<th>group: n variable mean (SD):</th>
<th>whole group</th>
<th>exercise/calcium</th>
<th>exercise/placebo</th>
<th>no exercise/calcium</th>
<th>no exercise/placebo</th>
</tr>
</thead>
<tbody>
<tr>
<td>age (y)</td>
<td>14.8 (1.4)</td>
<td>14.7 (1.3)</td>
<td>14.9 (1.5)</td>
<td>15.0 (1.4)</td>
<td>14.5 (1.2)</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>54.6 (9.7)</td>
<td>54.3 (9.6)</td>
<td>52.8 (8.5)</td>
<td>56.0 (10.6)</td>
<td>55.3 (10.5)</td>
</tr>
<tr>
<td>height (cm)</td>
<td>163.8 (6.4)</td>
<td>163.3 (7.0)</td>
<td>165.3 (6.4)</td>
<td>163.2 (5.8)</td>
<td>162.8 (6.6)</td>
</tr>
<tr>
<td>maturation (mo)*</td>
<td>21.6 (18.6)</td>
<td>21.0 (17.8)</td>
<td>22.1 (17.5)</td>
<td>21.2 (15.9)</td>
<td>22.2 (23.2)</td>
</tr>
<tr>
<td>breast stage</td>
<td>3.9 (0.9)</td>
<td>3.9 (0.8)</td>
<td>3.9 (1.0)</td>
<td>3.9 (0.8)</td>
<td>3.7 (1.0)</td>
</tr>
<tr>
<td>pubic hair stage</td>
<td>3.8 (1.0)</td>
<td>3.6 (1.1)</td>
<td>3.9 (1.0)</td>
<td>4.1 (0.9)</td>
<td>3.6 (1.0)</td>
</tr>
<tr>
<td>body fat (%)</td>
<td>29.1 (6.5)</td>
<td>28.2 (6.7)</td>
<td>26.7 (5.5)</td>
<td>30.9 (6.1)</td>
<td>30.8 (7.0)</td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>35.8 (5.0)</td>
<td>36.2 (5.6)</td>
<td>35.9 (4.1)</td>
<td>35.9 (5.4)</td>
<td>35.4 (5.1)</td>
</tr>
<tr>
<td>dietary calcium (mg/d)</td>
<td>943 (387)</td>
<td>911 (411)</td>
<td>989 (372)</td>
<td>973 (437)</td>
<td>907 (345)</td>
</tr>
<tr>
<td>TBBMD (g/cm2)</td>
<td>0.883 (0.09)</td>
<td>0.879 (0.09)</td>
<td>0.882 (0.09)</td>
<td>0.877 (0.10)</td>
<td>0.893 (0.09)</td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>2.23 (0.32)</td>
<td>2.24 (0.33)</td>
<td>2.244 (0.36)</td>
<td>2.201 (0.33)</td>
<td>2.23 (0.30)</td>
</tr>
<tr>
<td>FNBMD (g/cm2)</td>
<td>0.915 (0.12)</td>
<td>0.918 (0.15)</td>
<td>0.915 (0.12)</td>
<td>0.918 (0.11)</td>
<td>0.91 (0.11)</td>
</tr>
<tr>
<td>Troch. BMD (g/cm2)</td>
<td>0.759 (0.12)</td>
<td>0.764 (0.15)</td>
<td>0.743 (0.10)</td>
<td>0.753 (0.12)</td>
<td>0.772 (0.10)</td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm2)</td>
<td>0.927 (0.14)</td>
<td>0.915 (0.16)</td>
<td>0.905 (0.12)</td>
<td>0.942 (0.15)</td>
<td>0.946 (0.11)</td>
</tr>
</tbody>
</table>

* maturation was measured as months past menarche

There were no significant differences between groups for any of these variables.
between the four groups for any of the dependent variables or the variables used to match subjects.

**Program Compliance, Calcium Intake, Strength and Body Composition Changes:**

Mean compliance with the weight-training and calcium/placebo-supplementation program is summarized in Table 4.3. There were no significant differences between groups for either compliance variable. Calcium/placebo compliance is stated as a percentage of the maximum possible days of supplementation beginning with the day the subjects received their tablets and ending the day they had their last bone mineral measures taken. The mean calcium/placebo compliance for all subjects was $75.8 \pm 19.5\%$. Only six subjects had less than 50% compliance.

Weight-training compliance is expressed as a percentage of the required 134 workout sessions over the 18 months. The number of workout sessions was calculated by multiplying the number of weeks of study duration by two (workout sessions per week required for strength improvements), minus rest weeks incorporated for training periodization. The mean compliance for the weight-training group was $48.3 \pm 35.7\%$.

Physical activity records revealed consistent levels of activity for each subject, however, as a group, activity ranged from quite sedentary, e.g., walking, to quite active, e.g., regular (3x/wk) school or community sport leagues.

Table 4.4 summarizes dietary, supplemental, and total calcium intake for the groups. The overall mean for total calcium intake was $1273 \pm 497$ mg/d. The
Table 4.3 Program Compliance (subject set 2, n=87)

<table>
<thead>
<tr>
<th>compliance mean % (SD):</th>
<th>n</th>
<th>calcium/placebo</th>
<th>weight-training</th>
</tr>
</thead>
<tbody>
<tr>
<td>whole group</td>
<td>87</td>
<td>75.8 (19.5)</td>
<td>48.3 (35.7)</td>
</tr>
<tr>
<td>exercise/calcium</td>
<td>24</td>
<td>75.1 (23.6)</td>
<td>46.4 (35.2)</td>
</tr>
<tr>
<td>exercise/placebo</td>
<td>21</td>
<td>76.7 (16.5)</td>
<td>50.4 (37.1)</td>
</tr>
<tr>
<td>no exercise/calcium</td>
<td>20</td>
<td>74.4 (18.7)</td>
<td>N/A</td>
</tr>
<tr>
<td>no exercise/placebo</td>
<td>22</td>
<td>76.8 (19.2)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

There were no significant differences between groups for either compliance variable.

Table 4.4 Calcium Intake (subject set 2, n=87)

<table>
<thead>
<tr>
<th>mean mg/d (SD):</th>
<th>n</th>
<th>dietary intake</th>
<th>supplemented intake</th>
<th>total intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>whole group</td>
<td>87</td>
<td>894 (322)</td>
<td>743 (213)</td>
<td>1273 (497)</td>
</tr>
<tr>
<td>exercise/calcium</td>
<td>24</td>
<td>858 (334)</td>
<td>751 (236)</td>
<td>1609 (394)</td>
</tr>
<tr>
<td>exercise/placebo</td>
<td>21</td>
<td>982 (342)</td>
<td>N/A</td>
<td>982 (342)</td>
</tr>
<tr>
<td>no exercise/calcium</td>
<td>20</td>
<td>886 (351)</td>
<td>733 (185)</td>
<td>1653 (374)</td>
</tr>
<tr>
<td>no exercise/placebo</td>
<td>22</td>
<td>856 (260)</td>
<td>N/A</td>
<td>856 (260)</td>
</tr>
</tbody>
</table>

There were no significant differences between groups for dietary intake.

Table 4.5 Pre and Post Strength Measures and Changes (subject set 2, n=87)

<table>
<thead>
<tr>
<th>mean (SD):</th>
<th>n</th>
<th>strength test:</th>
<th>baseline (lbs)</th>
<th>final (lbs)</th>
<th>change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>group:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>whole group</td>
<td>87</td>
<td>bench press</td>
<td>60.9 (12.9)</td>
<td>64.0 (12.0)</td>
<td>5.1 (17.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>leg press</td>
<td>204.5 (38.5)</td>
<td>231.5 (57.5)</td>
<td>13.2 (23.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60.0 (14.7)</td>
<td>65.3 (10.2)</td>
<td>8.8 (23.7)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>leg press</td>
<td>208.3 (42.4)</td>
<td>231.0 (41.2)</td>
<td>10.9 (19.2)</td>
</tr>
<tr>
<td>exercise/calcium</td>
<td>24</td>
<td>bench press</td>
<td>61.9 (6.8)</td>
<td>65.3 (9.6)</td>
<td>5.5 (12.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>leg press</td>
<td>207.1 (29.8)</td>
<td>258.0 (78.3)</td>
<td>24.6 (33.8)</td>
</tr>
<tr>
<td>exercise/placebo</td>
<td>21</td>
<td>bench press</td>
<td>63.0 (16.2)</td>
<td>66.1 (18.0)</td>
<td>4.9 (13.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>leg press</td>
<td>211.0 (43.3)</td>
<td>215.7 (43.1)</td>
<td>2.2 (8.7)</td>
</tr>
<tr>
<td>no exercise/calcium</td>
<td>20</td>
<td>bench press</td>
<td>59.1 (12.3)</td>
<td>60.3 (9.6)</td>
<td>2.0 (13.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>leg press</td>
<td>191.4 (36.1)</td>
<td>215.8 (47.9)</td>
<td>12.7 (17.6)</td>
</tr>
<tr>
<td>no exercise/placebo</td>
<td>22</td>
<td>bench press</td>
<td>59.1 (12.3)</td>
<td>60.3 (9.6)</td>
<td>2.0 (13.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>leg press</td>
<td>191.4 (36.1)</td>
<td>215.8 (47.9)</td>
<td>12.7 (17.6)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>exercise vs. non exercise group strength changes: (actual values)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>bench press</td>
<td>0.04*</td>
</tr>
<tr>
<td>leg press</td>
<td>0.04*</td>
</tr>
</tbody>
</table>

There were no significant differences between groups for baseline strength measures.
group with the lowest mean intake was the no exercise/placebo group receiving 856 ± 260 mg/d and the group with the highest intake was the no-exercise/calcium group receiving 1653 ± 374 mg/d. Two groups were above the Canadian RNI of 1000 mg/d as well as above the U. S. RDA of 1200 mg/d. The other two groups were slightly under the Canadian RNI for 13-15 year olds. There was an insignificant relationship between baseline dietary calcium intake and baseline total body bone mineral content, femoral neck, spine, and total body bone mineral densities, but, there was a significant relationship (r=0.21, P=0.05) with baseline trochanter bone mineral density. Dietary calcium intake, estimated from three-day food records, was not significantly different between groups initially or between pre- and post-measures. Correlation analysis between total calcium intake and changes in bone mineral from 0-18 months was completed to test for the possibility of a dose-response relationship. There was a trend (P=0.08) noted for a positive relationship (r=0.2) at the trochanter.

There were three subjects that did no weight training at all and 19 subjects had less than 50% compliance with the weight-training program. Despite low compliance, there were still significantly greater percent change increases in upper body (bench press) (P=0.04) and lower body (leg press) (P=0.04) strength in the weight-training group than in the non weight-training group (table 4.5). There were no significant differences between groups for baseline strength measures. Correlation between exercise compliance and changes in bone mineral from 0-18 months was completed to test for the possibility of a dose-response relationship. A significant (P<0.01) negative correlation (r=-0.4) was found with total body bone mineral density (r=-0.45) and content (r=-0.4) and with spine bone mineral density (r=-0.43), and a trend was noted for a positive correlation (r=0.23, P=0.06) with the femoral neck bone mineral density.
Body weight, height and lean mass all changed significantly with time (P< 0.01), but changes were not significantly different between the four different treatment groups with time. There was a trend for change with time for percent body fat (P=0.06) and for differences between groups for body weight (P=0.06) (table 4.8). Menstrual records revealed that all subjects had between 13 and 17 menstrual periods throughout the duration of the study.

**Bone Mineral Changes:**

ANCOVA, using change in body weight as the covariate, of the 87 subjects indicated that there were very few differences between the changes in the bone mineral measures between the different treatment groups for any of the time periods, 0-6, 6-18, and 0-18 months (tables 4.6, 4.7, 4.8 respectively). Significant changes were not necessarily expected to be seen in this data set because the low compliance subjects were still included. Also, this data set had only nine complete blocks of four subjects left out of the original 27 blocks, because of the subjects who dropped out.

There was only one significant interaction between calcium supplementation and weight training for total body bone mineral content change between 6-18 months (P=0.09). This interaction resulted in calcium supplementation having a positive effect in the exercise groups and a negative effect in the no-exercise groups. There was also a significant positive effect of calcium at the trochanter from 0-6 months (P=0.03) and from 0-18 months (P=0.02). Body weight change was a significant cofactor (P≤ 0.03) for most bone mineral measures, for all time periods, except for the trochanter and lumbar spine between 0-6 months and for the trochanter between 6-18 months, indicating the relationship between body weight and bone mineral and the necessity to account for it.
Table 4.6 Subject Changes 0-6 Months (subject set 2, n=87)(unadjusted means)

<table>
<thead>
<tr>
<th>group: n mean change (SD):</th>
<th>whole group</th>
<th>exercise/calcium</th>
<th>exercise/placebo</th>
<th>no exercise/calcium</th>
<th>no exercise/placebo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>87</td>
<td>24</td>
<td>21</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>1.5 (2.5)</td>
<td>1.2 (2.6)</td>
<td>1.4 (1.7)</td>
<td>0.9 (1.7)</td>
<td>2.7 (3.2)</td>
</tr>
<tr>
<td>height (cm)</td>
<td>1.7 (1.8)</td>
<td>2.1 (2.7)</td>
<td>1.4 (1.2)</td>
<td>1.5 (1.0)</td>
<td>2.1 (1.4)</td>
</tr>
<tr>
<td>body fat (%)</td>
<td>0.8 (2.5)</td>
<td>0.7 (2.5)</td>
<td>0.1 (1.4)</td>
<td>0.7 (2.0)</td>
<td>1.6 (3.6)</td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>0.8 (1.3)</td>
<td>0.8 (1.3)</td>
<td>1.2 (1.9)</td>
<td>0.3 (1.3)</td>
<td>1.0 (1.5)</td>
</tr>
<tr>
<td>TBBMD (g/cm2)</td>
<td>0.001 (0.02)</td>
<td>0.006 (0.02)</td>
<td>(-0.001 (0.02)</td>
<td>(-0.001 (0.02)</td>
<td>(-0.002 (0.03)</td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>0.104 (0.07)</td>
<td>0.102 (0.07)</td>
<td>0.084 (0.07)</td>
<td>0.108 (0.07)</td>
<td>0.121 (0.08)</td>
</tr>
<tr>
<td>FNBMD (g/cm2)</td>
<td>0.027 (0.03)</td>
<td>0.029 (0.03)</td>
<td>0.033 (0.03)</td>
<td>0.026 (0.03)</td>
<td>0.019 (0.03)</td>
</tr>
<tr>
<td>Troch. BMD (g/cm2)</td>
<td>0.010 (0.03)</td>
<td>0.022 (0.03)</td>
<td>0.005 (0.02)</td>
<td>0.011 (0.04)</td>
<td>0.001 (0.03)</td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm2)</td>
<td>0.032 (0.11)</td>
<td>0.047 (0.04)</td>
<td>0.045 (0.03)</td>
<td>(-0.004 (0.22)</td>
<td>0.036 (0.03)</td>
</tr>
</tbody>
</table>

Summary of significant changes by ANCOVA: (controlled for weight change)

- main positive effect of calcium at the trochanter: P = 0.03
- covariate weight change (all bone measures except trochanter and spine): <0.03
Table 4.7 Subject Changes 6-18 Months (subject set 2, n=87)(unadjusted means)

<table>
<thead>
<tr>
<th>group: n</th>
<th>mean change (SD)</th>
<th>whole group 87</th>
<th>exercise/calium 24</th>
<th>exercise/placebo 21</th>
<th>no exercise/calium 20</th>
<th>no exercise/placebo 22</th>
</tr>
</thead>
<tbody>
<tr>
<td>weight (kg)</td>
<td>2.3 (2.8)</td>
<td>2.2 (3.3)</td>
<td>2.4 (2.5)</td>
<td>2.1 (2.3)</td>
<td>2.3 (2.9)</td>
<td></td>
</tr>
<tr>
<td>height (cm)</td>
<td>0.6 (1.3)</td>
<td>0.8 (1.5)</td>
<td>0.7 (1.7)</td>
<td>0.2 (0.9)</td>
<td>0.5 (1.2)</td>
<td></td>
</tr>
<tr>
<td>body fat (%)</td>
<td>0.4 (2.4)</td>
<td>0.7 (3.0)</td>
<td>0.6 (2.0)</td>
<td>(-)0.3 (2.5)</td>
<td>0.5 (2.2)</td>
<td></td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>1.4 (1.3)</td>
<td>1.2 (1.3)</td>
<td>1.3 (1.5)</td>
<td>1.8 (0.8)</td>
<td>1.2 (1.5)</td>
<td></td>
</tr>
<tr>
<td>TBBMD (g/cm2)</td>
<td>0.017 (0.02)</td>
<td>0.021 (0.02)</td>
<td>0.015 (0.02)</td>
<td>0.015 (0.02)</td>
<td>0.018 (0.02)</td>
<td></td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>0.073 (0.07)</td>
<td>0.081 (0.08)</td>
<td>0.065 (0.06)</td>
<td>0.059 (0.05)</td>
<td>0.083 (0.07)</td>
<td></td>
</tr>
<tr>
<td>FNBMD (g/cm2)</td>
<td>0.005 (0.03)</td>
<td>0.007 (0.03)</td>
<td>(-)0.001 (0.03)</td>
<td>0.004 (0.04)</td>
<td>0.008 (0.04)</td>
<td></td>
</tr>
<tr>
<td>Troch. BMD (g/cm2)</td>
<td>0.010 (0.03)</td>
<td>0.014 (0.03)</td>
<td>0.007 (0.03)</td>
<td>0.005 (0.04)</td>
<td>0.013 (0.03)</td>
<td></td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm2)</td>
<td>0.022 (0.04)</td>
<td>0.014 (0.04)</td>
<td>0.024 (0.03)</td>
<td>0.018 (0.04)</td>
<td>0.031 (0.04)</td>
<td></td>
</tr>
</tbody>
</table>

Summary of significant changes by ANCOVA: (controlled for weight change)

<table>
<thead>
<tr>
<th>interaction of calcium and exercise for TBBMC (calcium was beneficial in the exercise group but not in the no-exercise group)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>covariate weight change (all bone measures except trochanter)</td>
<td>0.09</td>
</tr>
<tr>
<td>group: n</td>
<td>mean change (SD):</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>3.8 (3.8)</td>
</tr>
<tr>
<td>height (cm)</td>
<td>2.3 (2.5)</td>
</tr>
<tr>
<td>body fat (%)</td>
<td>1.2 (3.6)</td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>2.2 (2.0)</td>
</tr>
<tr>
<td>TBBMD (g/cm2)</td>
<td>0.018 (0.04)</td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>0.178 (0.12)</td>
</tr>
<tr>
<td>FNBM (g/cm2)</td>
<td>0.032 (0.04)</td>
</tr>
<tr>
<td>Troch. BMD (g/cm2)</td>
<td>0.022 (0.04)</td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm2)</td>
<td>0.066 (0.06)</td>
</tr>
</tbody>
</table>

Summary of significant changes by ANCOVA: (controlled for weight change)  
- main effect of calcium at trochanter: 0.02  
- covariate weight change (all bone measures): <0.001
4.3 Revised Subject Sets

To determine more clearly the effects of calcium and weight-training on bone of those subjects who actually complied with the program, two revised subject sets were formed from the 87 subjects who completed the study. The 19 exercisers and the six calcium/placebo subjects who had compliance below 50% were eliminated. Also, the 12 premenarcheal subjects were eliminated since their maturational status was unknown. The fact that maturational status greatly affects bone mineral accrual, with the time period around menarche being when peak bone mineral accrual occurs (Bailey et al., 1997) was another reason for eliminating the premenarcheal girls so they did not confound the results of the intervention. This provided a set of 50 subjects (exercise/calcium n=9, exercise/placebo n=9, no exercise/calcium n=16, no exercise/placebo n=16), subject set 3, who complied with, and completed the program, for further analysis. However, to analyze these subjects by means of the initial study design, using blocking, was not possible since now only one complete block of four subjects of the original 27 blocks remained. Therefore, post-stratification matching of the 50 subjects, matching on maturation first, because of its greatest effect on rate of bone accrual, and weight second, was done to form seven complete blocks of four subjects (subject set 4, n=28), one from each treatment group. This allowed for analysis using the original blocking design of the study and controlling for sources of bone mineral variation.

Analyses on both subject sets 3 and 4 were completed for comparison purposes. Bone mineral change results observed in subject set 4 were considered first, since more sources of variation were controlled for by the blocking design, then they were compared with the results observed in subject set 3.
4.4 Subject Set 3 Results - Subjects who completed the study and had >50% compliance (n=50)

Subject Set 4 Results - Subjects from set 3 matched to form blocks (n=28)

Baseline Descriptives, Program Compliance, Strength Changes and Calcium Intake:

Table 4.9 and table 4.10 present the initial means for the descriptive variables of these two subject sets, n=50 and n=28 respectively. ANOVA showed that there were no significant differences between the groups on any of these variables for either subject set 3 or 4. Tables 4.11 and 4.12 present the program compliance showing that exercise compliance was 83.2 ± 24.9% and 91.0 ± 22.4% and calcium/placebo compliance was 84.0 ± 14.8% and 84.1 ± 14.6% for the groups of 50 and 28 subjects, respectively. Tables 4.13 and 4.14 show that upper and lower body strength changes were significantly greater (P≤0.03) in the exercise groups than in the control groups in subject set 3 between 0-6 mo. and subject set 4 (n=28) (P=0.04). Only lower body strength was significantly different in subject set 3 between 0-18 mo. There were no significant differences between groups in strength changes between 6-18 mo. in either subject set, for baseline strength measures, or for either of the two compliance variables.

Tables 4.15 and 4.16 show the mean dietary, supplemented and total calcium intakes. There were no significant differences between groups for dietary intake. For both subject sets 3 and 4 the lowest group mean for total calcium intake was observed in the no-exercise/placebo groups (872 and 816 mg/d, respectively) and the highest group mean for total calcium intake was observed in the exercise/calcium groups (1749 and 1790 mg/d). The supplemented groups ingested just over 800 mg/d more calcium, approximately 86% more, than the unsupplemented groups for both subject sets 3 and 4.
Table 4.9 Baseline Descriptive Statistics (subject set 3, n=50)(unadjusted means)

<table>
<thead>
<tr>
<th>variable</th>
<th>whole group</th>
<th>exercise/calcium</th>
<th>exercise/placebo</th>
<th>no exercise/calcium</th>
<th>no exercise/placebo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean (SD)</td>
<td>mean (SD)</td>
<td>mean (SD)</td>
<td>mean (SD)</td>
<td>mean (SD)</td>
</tr>
<tr>
<td>age (y)</td>
<td>15.1 (1.4)</td>
<td>15.5 (1.5)</td>
<td>15.2 (1.6)</td>
<td>15.3 (1.5)</td>
<td>14.8 (1.3)</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>56.8 (9.8)</td>
<td>56.3 (8.5)</td>
<td>55.5 (7.7)</td>
<td>56.9 (11.1)</td>
<td>57.7 (11.1)</td>
</tr>
<tr>
<td>height (cm)</td>
<td>164.0 (6.6)</td>
<td>165.7 (7.6)</td>
<td>164.4 (7.4)</td>
<td>162.6 (6.2)</td>
<td>164.3 (6.3)</td>
</tr>
<tr>
<td>maturation (mo)*</td>
<td>27.4 (16.7)</td>
<td>35.0 (12.3)</td>
<td>27.3 (8.4)</td>
<td>24.3 (15.1)</td>
<td>26.2 (22.7)</td>
</tr>
<tr>
<td>breast (stage)</td>
<td>4.1 (0.8)</td>
<td>4.4 (0.5)</td>
<td>4.1 (0.9)</td>
<td>3.94 (0.8)</td>
<td>3.9 (0.8)</td>
</tr>
<tr>
<td>pubic hair (stage)</td>
<td>4.0 (0.9)</td>
<td>4.0 (1.0)</td>
<td>4.2 (1.0)</td>
<td>4.12 (0.9)</td>
<td>3.8 (0.9)</td>
</tr>
<tr>
<td>body fat (%)</td>
<td>30.6 (6.3)</td>
<td>28.6 (6.0)</td>
<td>28.3 (6.1)</td>
<td>31.5 (6.5)</td>
<td>32.1 (6.2)</td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>36.7 (5.3)</td>
<td>37.6 (6.3)</td>
<td>37.0 (3.4)</td>
<td>36.3 (5.9)</td>
<td>36.3 (5.5)</td>
</tr>
<tr>
<td>dietary calcium (mg/d)</td>
<td>980 (446)</td>
<td>945 (490)</td>
<td>1138 (486)</td>
<td>974 (481)</td>
<td>918 (381)</td>
</tr>
<tr>
<td>TBBMD (g/cm2)</td>
<td>0.906 (0.09)</td>
<td>0.907 (0.07)</td>
<td>0.914 (0.08)</td>
<td>0.889 (0.1)</td>
<td>0.917 (0.09)</td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>2.313 (0.31)</td>
<td>2.399 (0.28)</td>
<td>2.354 (0.34)</td>
<td>2.230 (0.35)</td>
<td>2.323 (0.27)</td>
</tr>
<tr>
<td>FNBMD (g/cm2)</td>
<td>0.928 (0.12)</td>
<td>0.961 (0.16)</td>
<td>0.943 (0.11)</td>
<td>0.919 (0.11)</td>
<td>0.910 (0.01)</td>
</tr>
<tr>
<td>Troch. BMD (g/cm2)</td>
<td>0.768 (0.13)</td>
<td>0.792 (0.20)</td>
<td>0.768 (0.11)</td>
<td>0.753 (0.12)</td>
<td>0.769 (0.09)</td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm2)</td>
<td>0.957 (0.13)</td>
<td>0.968 (0.14)</td>
<td>0.927 (0.11)</td>
<td>0.956 (0.15)</td>
<td>0.967 (0.10)</td>
</tr>
</tbody>
</table>

* maturation was measured as months past menarche.

There were no significant differences between groups for any of these variables.
Table 4.10 Baseline Descriptive Statistics for Matched Blocks (subject set 4, n=28)(unadjusted means)

<table>
<thead>
<tr>
<th>group: n variable mean: (SD)</th>
<th>whole group</th>
<th>exercise/calculator</th>
<th>exercise/placebo</th>
<th>no exercise/calculator</th>
<th>no exercise/placebo</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>age (y)</td>
<td>15.0 (1.4)</td>
<td>15.3 (1.7)</td>
<td>14.9 (1.7)</td>
<td>15.2 (0.8)</td>
<td>14.5 (1.2)</td>
</tr>
<tr>
<td>maturation (mo)*</td>
<td>29.2 (10.9)</td>
<td>30.4 (9.5)</td>
<td>26.8 (9.5)</td>
<td>27.6 (12.5)</td>
<td>32.0 (13.3)</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>54.8 (5.6)</td>
<td>53.4 (5.8)</td>
<td>53.8 (3.9)</td>
<td>54.1 (6.2)</td>
<td>57.7 (6.3)</td>
</tr>
<tr>
<td>height (cm)</td>
<td>163.2 (5.4)</td>
<td>162.1 (3.1)</td>
<td>162.6 (3.8)</td>
<td>162.7 (7.2)</td>
<td>165.4 (6.9)</td>
</tr>
<tr>
<td>body fat (%)</td>
<td>30.7 (5.9)</td>
<td>29.5 (6.6)</td>
<td>27.8 (6.3)</td>
<td>32.4 (5.7)</td>
<td>32.9 (4.3)</td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>35.4 (3.9)</td>
<td>35.1 (3.2)</td>
<td>36.2 (2.0)</td>
<td>34.3 (6.0)</td>
<td>36.1 (3.9)</td>
</tr>
<tr>
<td>dietary calcium (mg/d)</td>
<td>976 (379)</td>
<td>915 (377)</td>
<td>1220 (492)</td>
<td>955 (333)</td>
<td>816 (221)</td>
</tr>
<tr>
<td>TBBMD (g/cm2)</td>
<td>0.901 (0.08)</td>
<td>0.896 (0.07)</td>
<td>0.913 (0.06)</td>
<td>0.864 (0.08)</td>
<td>0.932 (0.09)</td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>2.289 (0.23)</td>
<td>2.294 (0.19)</td>
<td>2.288 (0.14)</td>
<td>2.164 (0.26)</td>
<td>2.411 (0.27)</td>
</tr>
<tr>
<td>FNBMVD (g/cm2)</td>
<td>0.937 (0.12)</td>
<td>0.941 (0.16)</td>
<td>0.945 (0.09)</td>
<td>0.915 (0.15)</td>
<td>0.947 (0.09)</td>
</tr>
<tr>
<td>Troch. BMD (g/cm2)</td>
<td>0.761 (0.13)</td>
<td>0.779 (0.22)</td>
<td>0.780 (0.10)</td>
<td>0.723 (0.11)</td>
<td>0.761 (0.08)</td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm2)</td>
<td>0.937 (0.09)</td>
<td>0.936 (0.09)</td>
<td>0.916 (0.05)</td>
<td>0.915 (0.14)</td>
<td>0.980 (0.08)</td>
</tr>
</tbody>
</table>

* maturation was measured as months past menarche.
There were no significant differences between groups for any of these variables.
Table 4.11 Program Compliance (subject set 3, n=50)

<table>
<thead>
<tr>
<th>group</th>
<th>n</th>
<th>calcium/placebo</th>
<th>weight-training</th>
</tr>
</thead>
<tbody>
<tr>
<td>whole group</td>
<td>50</td>
<td>84.0 (14.8)</td>
<td>83.2 (24.9)</td>
</tr>
<tr>
<td>exercise/calcium</td>
<td>9</td>
<td>84.5 (18.2)</td>
<td>80.3 (28.9)</td>
</tr>
<tr>
<td>exercise/placebo</td>
<td>9</td>
<td>88.6 (7.9)</td>
<td>86.2 (21.6)</td>
</tr>
<tr>
<td>no exercise/calcium</td>
<td>16</td>
<td>81.7 (15.8)</td>
<td>N/A</td>
</tr>
<tr>
<td>no exercise/placebo</td>
<td>16</td>
<td>83.3 (15.5)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

There were no significant differences between groups on either compliance variable.

Table 4.12 Program Compliance (subject set 4, n=28)

<table>
<thead>
<tr>
<th>group</th>
<th>n</th>
<th>calcium/placebo</th>
<th>weight-training</th>
</tr>
</thead>
<tbody>
<tr>
<td>whole group</td>
<td>28</td>
<td>84.1 (14.6)</td>
<td>91.0 (22.4)</td>
</tr>
<tr>
<td>range of % compliance</td>
<td>28</td>
<td>53.7 - 97.8</td>
<td>53.7 - 123.9</td>
</tr>
<tr>
<td>exercise/calcium</td>
<td>7</td>
<td>87.5 (15.2)</td>
<td>88.5 (27.5)</td>
</tr>
<tr>
<td>exercise/placebo</td>
<td>7</td>
<td>90.7 (5.4)</td>
<td>93.5 (17.7)</td>
</tr>
<tr>
<td>no exercise/calcium</td>
<td>7</td>
<td>76.7 (17.5)</td>
<td>N/A</td>
</tr>
<tr>
<td>no exercise/placebo</td>
<td>7</td>
<td>81.3 (15.8)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

There were no significant differences between groups for either compliance variable.

*note: compliance was above 100% in some subjects because 2 exercise sessions per week were required (and used in compliance calculations), however, 3 sessions per week were recommended and set out in the program directions to the subjects.
Table 4.13 Strength Measures and Changes (subject set 3, n=50)

<table>
<thead>
<tr>
<th>mean (SD):</th>
<th>group:</th>
<th>n</th>
<th>strength test:</th>
<th>baseline (lbs)</th>
<th>6 mo. (lbs)</th>
<th>final (lbs)</th>
<th>change (%)</th>
<th>0-18 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>whole group</td>
<td>50</td>
<td>bench press</td>
<td>62.6 (14.8)</td>
<td>65.0 (13.7)</td>
<td>65.1 (13.6)</td>
<td>4.0 (14.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>leg press</td>
<td>208.4 (38.9)</td>
<td>228.8 (49.6)</td>
<td>245.6 (65.2)</td>
<td>17.8 (25.6)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>exercise/calium</td>
<td>9</td>
<td>bench press</td>
<td>61.1 (17.6)</td>
<td>65.6 (15.1)</td>
<td>62.8 (11.1)</td>
<td>2.8 (9.9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>leg press</td>
<td>208.9 (48.1)</td>
<td>248.9 (57.5)</td>
<td>232.9 (22.1)</td>
<td>11.5 (9.9)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>exercise/placebo</td>
<td>9</td>
<td>bench press</td>
<td>66.7 (5.0)</td>
<td>71.1 (6.0)</td>
<td>71.2 (8.3)</td>
<td>6.7 (16.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>leg press</td>
<td>223.3 (22.3)</td>
<td>273.3 (24.5)</td>
<td>332.5 (73.9)</td>
<td>48.9 (37.1)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>no exercise/calium</td>
<td>16</td>
<td>bench press</td>
<td>64.4 (17.5)</td>
<td>65.0 (15.9)</td>
<td>68.2 (18.9)</td>
<td>5.9 (17.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>leg press</td>
<td>216.2 (40.8)</td>
<td>210.6 (46.7)</td>
<td>220.0 (45.1)</td>
<td>1.8 (8.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>no exercise/placebo</td>
<td>16</td>
<td>bench press</td>
<td>59.4 (14.3)</td>
<td>61.3 (13.6)</td>
<td>60.7 (11.6)</td>
<td>2.2 (13.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>leg press</td>
<td>190.7 (35.3)</td>
<td>210.6 (40.2)</td>
<td>224.3 (48.5)</td>
<td>17.6 (18.9)</td>
<td></td>
</tr>
</tbody>
</table>

There were no significant differences between groups for baseline strength measures.

Table 4.14 Pre to Post Strength Changes (subject set 4, n=28)

<table>
<thead>
<tr>
<th>group: n</th>
<th>variable mean (SD):</th>
<th>weight-training</th>
<th>no weight-training</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bench press (lbs)</td>
<td>6.4 (9.2)</td>
<td>(-)0.9 (5.4)</td>
<td>0.04*</td>
</tr>
<tr>
<td></td>
<td>leg press (lbs)</td>
<td>77.7 (74.4)</td>
<td>15.4 (30.7)</td>
<td>0.01*</td>
</tr>
</tbody>
</table>

* P values indicate significant change in strength measures between the weight-training and no weight-training groups.
Table 4.15 Calcium Intake (subject set 3, n=50)

<table>
<thead>
<tr>
<th>mean mg/d (SD):</th>
<th>n</th>
<th>dietary intake</th>
<th>supplemented intake</th>
<th>total intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>group:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>whole group</td>
<td>50</td>
<td>939 (349)</td>
<td>814 (166)</td>
<td>1346 (510)</td>
</tr>
<tr>
<td>exercise/calcium</td>
<td>9</td>
<td>904 (348)</td>
<td>845 (162)</td>
<td>1749 (398)</td>
</tr>
<tr>
<td>exercise/placebo</td>
<td>9</td>
<td>1181 (433)</td>
<td>N/A</td>
<td>1181 (433)</td>
</tr>
<tr>
<td>no exercise/calcium</td>
<td>16</td>
<td>890 (352)</td>
<td>796 (161)</td>
<td>1686 (349)</td>
</tr>
<tr>
<td>no exercise/placebo</td>
<td>16</td>
<td>872 (258)</td>
<td>N/A</td>
<td>872 (258)</td>
</tr>
</tbody>
</table>

There were no significant differences between groups for dietary intake.

Table 4.16 Calcium Intake (subject set 4, n=28)

<table>
<thead>
<tr>
<th>mean mg/d (SD):</th>
<th>n</th>
<th>dietary intake</th>
<th>supplemented intake</th>
<th>total intake</th>
</tr>
</thead>
<tbody>
<tr>
<td>group:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>whole group</td>
<td>28</td>
<td>976 (379)</td>
<td>821 (168)</td>
<td>1387 (558)</td>
</tr>
<tr>
<td>range</td>
<td></td>
<td>231 - 1981</td>
<td>537 - 978</td>
<td>485 -2397</td>
</tr>
<tr>
<td>exercise/calcium</td>
<td>7</td>
<td>915 (377)</td>
<td>875 (152)</td>
<td>1790 (450)</td>
</tr>
<tr>
<td>range</td>
<td></td>
<td>232 - 1405</td>
<td>537 - 965</td>
<td></td>
</tr>
<tr>
<td>exercise/placebo</td>
<td>7</td>
<td>1220 (492)</td>
<td>N/A</td>
<td>1220 (492)</td>
</tr>
<tr>
<td>range</td>
<td></td>
<td>536 - 1981</td>
<td></td>
<td></td>
</tr>
<tr>
<td>no exercise/calcium</td>
<td>7</td>
<td>955 (333)</td>
<td>767 (176)</td>
<td>1722 (420)</td>
</tr>
<tr>
<td>range</td>
<td></td>
<td>509 - 1485</td>
<td>543 - 978</td>
<td></td>
</tr>
<tr>
<td>no exercise/placebo</td>
<td>7</td>
<td>816 (221)</td>
<td>N/A</td>
<td>816 (221)</td>
</tr>
<tr>
<td>range</td>
<td></td>
<td>485 - 1156</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There were no significant differences between groups for dietary intake.
Bone Mineral Changes:

Tables 4.17 through 4.22 show the mean changes and percent changes of the bone mineral variables from 0-6 months, 6-18 months and 0-18 months for the n=50 and n=28 subject sets. Changes between 0-6 months were considered as part of the remodeling transient, and changes between 6-18 months were considered as part of the true intervention period of the study. The changes between 0-18 months are presented to indicate the changes observed if the bone remodeling transient was not considered.

The results of the repeated measures ANCOVA, using covariates of maturation and body weight change indicated that weight change was a significant covariate for most bone mineral measures in both subject sets 3 and 4, except total body bone mineral content and trochanter bone mineral density (n=28). Maturation (months past menarche) was not a significant covariate for any measure, since it changed the same amount in all subjects. In subject set 4 there were significant changes (P≤0.01) across the three time periods (factor effect) for all bone measures, except for total body bone mineral density, using weight as a covariate, but no significant differences between the groups (group effect) were found across time. These results for change across the three time periods (factor effect) were the same for subject set 3 (n=50), except there was no significant effect at the trochanter. When maturation was used as the covariate, however, a significant factor effect (P=0.04) was noted at the trochanter.

A significant interaction between the treatment groups across time was noted in the trochanter (P=0.03), the femoral neck (P=0.05) and the lumbar spine (P=0.08) which indicated that one treatment group was changing at a different rate across time than the other treatment groups (subject set 4, n=28). The bone density
Table 4.17 Subject Changes 0-6 Months (subject set 3, n=50) (unadjusted means)

<table>
<thead>
<tr>
<th>group (n):</th>
<th>whole group (50)</th>
<th>exercise/calcium (9)</th>
<th>exercise/placebo (9)</th>
<th>no exercise/calcium (16)</th>
<th>no exercise/placebo (16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean change (SD):</td>
<td>mean change</td>
<td>mean change</td>
<td>% change</td>
<td>mean change</td>
<td>% change</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>1.2 (2.6)</td>
<td>0.2 (1.4)</td>
<td>0.6 (2.6)</td>
<td>0.7 (2.1)</td>
<td>1.6 (3.3)</td>
</tr>
<tr>
<td>height (cm)</td>
<td>1.2 (1.1)</td>
<td>0.8 (0.9)</td>
<td>0.5 (0.6)</td>
<td>0.8 (0.7)</td>
<td>0.5 (0.4)</td>
</tr>
<tr>
<td>body fat (%)</td>
<td>0.7 (2.7)</td>
<td>0.5 (1.5)</td>
<td>2.6 (5.5)</td>
<td>0.0 (1.8)</td>
<td>0.2 (5.9)</td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>0.5 (1.3)</td>
<td>0.2 (1.2)</td>
<td>0.7 (3.2)</td>
<td>0.8 (0.8)</td>
<td>2.1 (2.1)</td>
</tr>
<tr>
<td>TBBMD (g/cm²)</td>
<td>(-0.007 (0.02))</td>
<td>(-0.007 (0.01))</td>
<td>(-0.8 (1.6))</td>
<td>(-0.010 (0.02))</td>
<td>(-1.0 (2.0))</td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>0.085 (0.07)</td>
<td>0.057 (0.05)</td>
<td>2.5 (2.3)</td>
<td>0.045 (0.04)</td>
<td>2.0 (1.8)</td>
</tr>
<tr>
<td>FNBMD (g/cm²)</td>
<td>0.019 (0.03)</td>
<td>0.017 (0.02)</td>
<td>1.8 (2.4)</td>
<td>0.025 (0.03)</td>
<td>2.7 (3.1)</td>
</tr>
<tr>
<td>Troch. BMD (g/cm²)</td>
<td>0.001 (0.03)</td>
<td>0.008 (0.03)</td>
<td>0.8 (3.6)</td>
<td>(-0.003 (0.01))</td>
<td>(-0.4 (1.8))</td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm²)</td>
<td>0.033 (0.03)</td>
<td>0.030 (0.05)</td>
<td>3.6 (4.8)</td>
<td>0.024 (0.02)</td>
<td>2.6 (1.7)</td>
</tr>
</tbody>
</table>

Summary of significant changes by ANCOVA: (controlled for weight change)

Interaction of calcium and exercise at the femoral neck (calcium was beneficial in no-exercise group but not in exercise group)

P value

0.07
<table>
<thead>
<tr>
<th>Group (n)</th>
<th>Variable Mean (SD)</th>
<th>Whole Group (28)</th>
<th>Exercise/Calcium (7)</th>
<th>Exercise/Placebo (7)</th>
<th>No Exercise/Calcium (7)</th>
<th>No Exercise/Placebo (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean Change</td>
<td>Mean Change % Change</td>
<td>Mean Change % Change</td>
<td>Mean Change % Change</td>
<td>Mean Change % Change</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>1.1 (1.9)</td>
<td>0.5 (1.4)</td>
<td>1.2 (2.8)</td>
<td>1.4 (1.1)</td>
<td>2.6 (2.2)</td>
<td>0.0 (1.4)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.9 (.9)</td>
<td>0.8 (1.0)</td>
<td>0.5 (0.7)</td>
<td>0.9 (0.1)</td>
<td>0.6 (0.5)</td>
<td>0.5 (0.7)</td>
</tr>
<tr>
<td>Body Fat (%)</td>
<td>0.3 (1.8)</td>
<td>0.2 (1.5)</td>
<td>1.7 (5.7)</td>
<td>0.2 (1.1)</td>
<td>0.5 (4.2)</td>
<td>0.3 (1.9)</td>
</tr>
<tr>
<td>Lean Mass (kg)</td>
<td>0.7 (1.1)</td>
<td>0.6 (0.9)</td>
<td>1.8 (2.7)</td>
<td>1.1 (0.6)</td>
<td>2.8 (1.6)</td>
<td>0.1 (1.4)</td>
</tr>
<tr>
<td>TBBMD (g/cm²)</td>
<td>(-0.008 (0.02)</td>
<td>(-0.006 (0.01))</td>
<td>(-0.06 (1.5))</td>
<td>(-0.005 (0.02))</td>
<td>(-0.5 (1.7))</td>
<td>(-0.006 (0.02))</td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>0.070 (0.04)</td>
<td>0.067 (0.04)</td>
<td>3.0 (2.1)</td>
<td>0.060 (0.04)</td>
<td>2.6 (1.5)</td>
<td>0.078 (0.03)</td>
</tr>
<tr>
<td>FNBMD (g/cm²)</td>
<td>0.019 (0.03)</td>
<td>0.023 (0.02)</td>
<td>2.4 (2.4)</td>
<td>0.037 (0.02)</td>
<td>3.9 (2.1)</td>
<td>0.023 (0.03)</td>
</tr>
<tr>
<td>Troch. BMD (g/cm²)</td>
<td>0.002 (0.02)</td>
<td>0.011 (0.03)</td>
<td>1.3 (4.0)</td>
<td>(-0.002 (0.02)</td>
<td>(-0.3 (2.0))</td>
<td>0.009 (0.02)</td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm²)</td>
<td>0.031 (0.02)</td>
<td>0.045 (0.03)</td>
<td>5.0 (4.1)</td>
<td>0.028 (0.01)</td>
<td>3.0 (1.7)</td>
<td>0.028 (0.02)</td>
</tr>
</tbody>
</table>

Summary of significant changes by ANCOVA (controlled for weight change)

<table>
<thead>
<tr>
<th>Interaction of calcium and exercise at the femoral neck (calcium was beneficial in no-exercise group but not in exercise group)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>interaction of calcium and exercise at the femoral neck (calcium was beneficial in no-exercise group but not in exercise group)</td>
<td>0.04</td>
</tr>
<tr>
<td>main positive effect of calcium at the lumbar spine</td>
<td>0.04</td>
</tr>
<tr>
<td>group: (n) mean change (SD):</td>
<td>whole group (50) mean change</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>2.4 (2.5)</td>
</tr>
<tr>
<td>height (cm)</td>
<td>0.1 (0.8)</td>
</tr>
<tr>
<td>body fat (%)</td>
<td>0.3 (2.3)</td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>1.4 (1.2)</td>
</tr>
<tr>
<td>TBBMD (g/cm2)</td>
<td>0.011 (0.02)</td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>0.052 (0.05)</td>
</tr>
<tr>
<td>FNBMD (g/cm2)</td>
<td>0.001 (0.03)</td>
</tr>
<tr>
<td>Troch. BMD (g/cm2)</td>
<td>0.010 (0.04)</td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm2)</td>
<td>0.015 (0.04)</td>
</tr>
</tbody>
</table>

Summary of significant changes by ANCOVA: (controlled for weight change)
there were no significant interactions or main effects of calcium and exercise
Table 4.20 Subject Changes 6-18 Months (subject set 4, n=28) (unadjusted means)

<table>
<thead>
<tr>
<th>variable</th>
<th>mean change</th>
<th>% change</th>
<th>mean change</th>
<th>% change</th>
<th>mean change</th>
<th>% change</th>
<th>mean change</th>
<th>% change</th>
<th>mean change</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>weight (kg)</td>
<td>2.2 (2.6)</td>
<td>6.5 (5.5)</td>
<td>1.2 (3.0)</td>
<td>2.3 (5.6)</td>
<td>1.5 (2.0)</td>
<td>2.7 (3.5)</td>
<td>2.3 (2.4)</td>
<td>3.9 (4.1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>height (cm)</td>
<td>0.2 (0.9)</td>
<td>0.1 (0.3)</td>
<td>0.2 (0.9)</td>
<td>0.1 (0.6)</td>
<td>0.7 (1.2)</td>
<td>0.4 (0.7)</td>
<td>0.1 (0.6)</td>
<td>0.1 (0.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>body fat (%)</td>
<td>0.2 (2.5)</td>
<td>7.0 (13.2)</td>
<td>(-0.4) (2.0)</td>
<td>(-0.6) (7.3)</td>
<td>(-1.2) (2.1)</td>
<td>(-3.5) (6.5)</td>
<td>0.7 (2.5)</td>
<td>2.7 (7.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>1.3 (1.4)</td>
<td>3.6 (3.0)</td>
<td>1.1 (1.9)</td>
<td>2.8 (5.2)</td>
<td>1.5 (1.3)</td>
<td>4.4 (3.2)</td>
<td>1.2 (1.7)</td>
<td>3.3 (4.6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBBMD (g/cm²)</td>
<td>0.008 (0.01)</td>
<td>1.4 (1.2)</td>
<td>0.006 (0.02)</td>
<td>0.7 (1.8)</td>
<td>0.007 (0.01)</td>
<td>0.7 (0.9)</td>
<td>0.006 (0.02)</td>
<td>0.8 (2.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>0.042 (0.04)</td>
<td>2.5 (1.2)</td>
<td>0.035 (0.05)</td>
<td>1.5 (2.2)</td>
<td>0.025 (0.04)</td>
<td>1.2 (1.8)</td>
<td>0.050 (0.05)</td>
<td>2.1 (2.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FNBMD (g/cm²)</td>
<td>(-0.008) (0.03)</td>
<td>0.8 (3.0)</td>
<td>(-0.018) (0.01)</td>
<td>(-1.9) (1.5)</td>
<td>(-0.025) (0.02)</td>
<td>(-2.7) (2.7)</td>
<td>0.002 (0.02)</td>
<td>0.2 (2.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Troch. BMD (g/cm²)</td>
<td>0.012 (0.03)</td>
<td>4.4 (4.2)</td>
<td>0.009 (0.03)</td>
<td>1.1 (4.4)</td>
<td>(-0.005) (0.02)</td>
<td>(-0.7) (2.2)</td>
<td>0.013 (0.02)</td>
<td>1.6 (2.9)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| L2-L4 BMD (g/cm²)| 0.014 (0.04)| (-0.015) (0.04)| (-1.5) (4.2)| 0.015 (0.02)| 1.6 (2.2)| 0.026 (0.04)| 2.7 (4.1)| 0.029 (0.04)| 2.2 (4.4)|}

Summary of significant changes by ANCOVA (controlled for weight change)

<table>
<thead>
<tr>
<th>interaction of calcium and exercise at the femoral neck (calcium was beneficial in the exercise group but not in the no-exercise group)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>main negative effect of exercise at the lumbar spine</td>
<td>0.04</td>
</tr>
<tr>
<td>main negative effect of calcium at the lumbar spine</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Table 4.21: Subject Changes 0-18 Months (subject set 3, n=50)(unadjusted means)

<table>
<thead>
<tr>
<th>group: (n)</th>
<th>whole group (50)</th>
<th>exercise/calcium (9)</th>
<th>exercise/placebo (9)</th>
<th>no exercise/calcium (16)</th>
<th>no exercise/placebo (16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean change (SD):</td>
<td>mean change</td>
<td>% change</td>
<td>mean change</td>
<td>% change</td>
<td>mean change</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>3.5 (3.3)</td>
<td>3.2 (2.8)</td>
<td>6.1 (5.3)</td>
<td>2.0 (2.5)</td>
<td>3.7 (4.9)</td>
</tr>
<tr>
<td>height (cm)</td>
<td>1.3 (1.4)</td>
<td>0.9 (1.4)</td>
<td>0.6 (0.8)</td>
<td>0.8 (1.1)</td>
<td>0.5 (0.7)</td>
</tr>
<tr>
<td>body fat (%)</td>
<td>1.0 (3.2)</td>
<td>2.1 (2.7)</td>
<td>9.6 (15.4)</td>
<td>(-0.4) (2.0)</td>
<td>(-0.5) (7.5)</td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>1.9 (1.8)</td>
<td>1.1 (1.9)</td>
<td>3.4 (5.3)</td>
<td>1.8 (2.0)</td>
<td>4.6 (5.5)</td>
</tr>
<tr>
<td>TBBMD (g/cm2)</td>
<td>0.004 (0.03)</td>
<td>0.004 (0.01)</td>
<td>0.5 (1.6)</td>
<td>(-0.003) (0.03)</td>
<td>(-0.2) (2.8)</td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>0.136 (0.10)</td>
<td>0.105 (0.06)</td>
<td>4.6 (2.6)</td>
<td>0.078 (0.07)</td>
<td>3.4 (3.0)</td>
</tr>
<tr>
<td>FNMBD (g/cm2)</td>
<td>0.020 (0.04)</td>
<td>0.024 (0.04)</td>
<td>2.2 (3.5)</td>
<td>0.015 (0.04)</td>
<td>1.8 (4.4)</td>
</tr>
<tr>
<td>Troch. BMD (g/cm2)</td>
<td>0.011 (0.03)</td>
<td>0.029 (0.03)</td>
<td>4.0 (4.8)</td>
<td>0.001 (0.03)</td>
<td>0.1 (3.7)</td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm2)</td>
<td>0.048 (0.04)</td>
<td>0.023 (0.03)</td>
<td>2.6 (2.7)</td>
<td>0.04 (0.03)</td>
<td>4.3 (3.2)</td>
</tr>
</tbody>
</table>

Summary of significant changes by ANCOVA: (controlled for weight change) P value 0.05
interaction of calcium and exercise at the lumbar spine (exercise and calcium together had a negative effect on change; calcium was beneficial in the no-exercise group but not in the exercise group)
main positive effect of calcium at the trochanter 0.03

Table 4.22: Subject Changes 0-18 Months (subject set 4, n=28)(unadjusted means)

<table>
<thead>
<tr>
<th>group: (n)</th>
<th>whole group (28)</th>
<th>exercise/calcium (7)</th>
<th>exercise/placebo (7)</th>
<th>no exercise/calcium (7)</th>
<th>no exercise/placebo (7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean change (SD):</td>
<td>mean change</td>
<td>% change</td>
<td>mean change</td>
<td>% change</td>
<td>mean change</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>3.3 (2.8)</td>
<td>4.1 (2.6)</td>
<td>7.7 (5.0)</td>
<td>2.6 (2.5)</td>
<td>4.9 (4.9)</td>
</tr>
<tr>
<td>height (cm)</td>
<td>1.1 (1.0)</td>
<td>1.0 (0.9)</td>
<td>0.6 (0.6)</td>
<td>1.1 (1.1)</td>
<td>0.7 (0.7)</td>
</tr>
<tr>
<td>body fat (%)</td>
<td>0.5 (2.7)</td>
<td>1.9 (3.0)</td>
<td>9.0 (17.5)</td>
<td>(-0.3) (2.2)</td>
<td>(-0.0) (8.5)</td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td>1.9 (1.8)</td>
<td>1.9 (1.4)</td>
<td>5.4 (4.1)</td>
<td>2.2 (2.1)</td>
<td>5.7 (5.7)</td>
</tr>
<tr>
<td>TBBMD (g/cm2)</td>
<td>0.001 (0.02)</td>
<td>0.006 (0.01)</td>
<td>0.8 (1.7)</td>
<td>0.002 (0.02)</td>
<td>0.2 (2.9)</td>
</tr>
<tr>
<td>TBBMC (kg)</td>
<td>0.112 (0.06)</td>
<td>0.126 (0.04)</td>
<td>5.6 (1.9)</td>
<td>0.096 (0.07)</td>
<td>4.2 (3.0)</td>
</tr>
<tr>
<td>FNMBD (g/cm2)</td>
<td>0.015 (0.03)</td>
<td>0.033 (0.04)</td>
<td>3.2 (3.3)</td>
<td>0.019 (0.03)</td>
<td>2.0 (2.9)</td>
</tr>
<tr>
<td>Troch. BMD (g/cm2)</td>
<td>0.008 (0.04)</td>
<td>0.041 (0.02)</td>
<td>5.6 (3.7)</td>
<td>0.006 (0.03)</td>
<td>0.7 (3.7)</td>
</tr>
<tr>
<td>L2-L4 BMD (g/cm2)</td>
<td>0.046 (0.04)</td>
<td>0.029 (0.02)</td>
<td>3.2 (2.3)</td>
<td>0.042 (0.03)</td>
<td>4.6 (3.7)</td>
</tr>
</tbody>
</table>

Summary of significant changes by ANCOVA: (controlled for weight change) P value 0.03
main positive effect of exercise at the trochanter
means, adjusted for weight, for the four treatment groups across time for each of these measures are plotted in figures 4.1, 4.2 and 4.3 respectively. Despite the matching of subjects, the large variation within the groups negates the possibility of seeing any significant group effects. The fact that a few more significant findings were noted using the matched blocked subjects may emphasize the importance of matching for maturation.

Results from ANCOVA, using body weight change as a covariate, to test for significant main effects of calcium and/or exercise and for interaction effects between these two independent variables, were as follows (table 4.23). There were no significant effects for total body bone mineral content or bone mineral density. Changes between 0-6 months included a significant interaction for femoral neck bone mineral density in both subject sets 3 and 4, (P=0.07 for n=50 and P=0.04 for n=28) indicating a beneficial effect of calcium in the no-exercise group but not in the exercise group. For changes in the lumbar spine (L2-L4) there was a significant positive effect of calcium (P<0.05) (set 4, n=28).

Between 6-18 months there was a significant interaction at the femoral neck (P=0.04) in the group of blocked subjects (set 4), which indicated a beneficial effect of calcium in the exercise group but not in the no-exercise group. A negative effect of calcium at the lumbar spine (P<0.04) was indicated by the average change in the supplemented groups being lower than in the unsupplemented groups. There was also a significant negative effect of exercise at this site (set 4, n=28), indicated by decreases, or smaller increases than other treatment groups, in bone mineral density.
Figure 4.1 Trochanter BMD Change With Time (significant interaction; $P=0.03$; subject set 4; $n=28$)

![Graph showing trochanter BMD change with time]

- Exercise/calcium
- Exercise/placebo
- No exercise/calcium
- No exercise/placebo

Figure 4.2 Femoral Neck BMD Change With Time (significant interaction; $P=0.05$; subject set 4; $n=28$)

![Graph showing femoral neck BMD change with time]

- Exercise/calcium
- Exercise/placebo
- No exercise/calcium
- No exercise/placebo

Study Measurement Period (months)
Figure 4.3  L2-L4 BMD Change With Time (significant interaction; P=0.08; subject set 4; n=28)
Table 4.23 Summary of P values for Interactions and Main Effects of Exercise and Supplemented Calcium on Bone Mineral Changes (subject set 3, n=50 and 4, n=28)

<table>
<thead>
<tr>
<th>main effects: P values</th>
<th>exercise</th>
<th>supplemented calcium</th>
<th>interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>bone mineral changes:</td>
<td>n=28</td>
<td>n=50</td>
<td>n=28</td>
</tr>
<tr>
<td><strong>TBBMD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-6 months</td>
<td>0.81</td>
<td>0.83</td>
<td>0.41</td>
</tr>
<tr>
<td>6-18 months</td>
<td>0.44</td>
<td>0.67</td>
<td>0.49</td>
</tr>
<tr>
<td>0-18 month</td>
<td>0.47</td>
<td>0.41</td>
<td>0.54</td>
</tr>
<tr>
<td><strong>TBBMC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-6 months</td>
<td>0.67</td>
<td>0.07</td>
<td>0.77</td>
</tr>
<tr>
<td>6-18 months</td>
<td>0.99</td>
<td>0.30</td>
<td>0.17</td>
</tr>
<tr>
<td>0-18 months</td>
<td>0.78</td>
<td>0.08</td>
<td>0.65</td>
</tr>
<tr>
<td><strong>FNBMD (FNBMAAD)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-6 months</td>
<td>0.11</td>
<td>0.49</td>
<td>0.42</td>
</tr>
<tr>
<td>6-18 months</td>
<td>0.57</td>
<td>0.70</td>
<td>0.88</td>
</tr>
<tr>
<td>0-18 months</td>
<td>0.06</td>
<td>0.70</td>
<td>0.32</td>
</tr>
<tr>
<td><strong>Troch. BMD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-6 months</td>
<td>0.14</td>
<td>0.87</td>
<td>0.18</td>
</tr>
<tr>
<td>6-18 months</td>
<td>0.66</td>
<td>0.71</td>
<td>0.37</td>
</tr>
<tr>
<td>0-18 months</td>
<td>0.03*</td>
<td>0.27</td>
<td>0.35</td>
</tr>
<tr>
<td><strong>L2-L4 BMD (L2-L4 BMAD)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-6 months</td>
<td>0.33</td>
<td>0.76</td>
<td>0.04* (0.10)</td>
</tr>
<tr>
<td>6-18 months</td>
<td>(-) 0.04*</td>
<td>0.15</td>
<td>(-)0.04*</td>
</tr>
<tr>
<td>0-18 months</td>
<td>0.20</td>
<td>0.15</td>
<td>0.53</td>
</tr>
</tbody>
</table>

Bold * and P values indicate significant results.
Bold numbers in brackets are P values indicating significance or trends in BMAD change.
Significant main effects of calcium or exercise were positive unless indicated by a "(-)" sign.
Positive significant interactions indicated that calcium was beneficial in the exercise group but not in the no-exercise group.
Negative significant interactions indicated that calcium was beneficial in the no-exercise group but not in the exercise group.
All effects were controlled for changes in body weight.
Between 0-18 months a significant interaction (P=0.05) was noted for lumbar spine bone mineral density (subject set 3, n=50), which indicated that exercise and calcium together had a negative effect on change, and calcium appeared beneficial for the non-exercise group but not for the exercise group. There were significant positive effects of calcium (subject set 3, n=50) and exercise (subject set 4, n=28) for trochanter bone mineral density. Figures 4.4 through 4.8 show the means for each bone mineral measure at 0, 6, and 18 months for each treatment group from subject set 4 (n=28) which demonstrate the pattern of change over the duration of the study. Figure 4.9 shows the changes in total body bone mineral content for subject set 4 (n=28), adjusted for weight change, between 0-6 and 6-18 months. Subject set 4 was chosen for representation in the figures because there was less variation amongst the groups due to the matching procedure. The changes in total body bone mineral content were all in the positive direction, due to growth and/or the intervention, but the differences in the changes between the treatment groups were not significant.

**Bone Mineral Apparent Density (BMAD):**

BMAD was calculated for femoral neck and lumbar spine in both subject sets 3 and 4. Repeated measures ANCOVA revealed significant changes across time in lumbar spine BMAD in both subject sets, but no significant differences between treatment groups across time. This result was the same as for the areal density analyses of these sites. For changes in femoral neck BMAD, only a trend (P=0.08) for change across time was noted in subject set 4 (n=28).
Figure 4.4 Total Body BMD Means for Treatment Groups (subject set 4, n=28)

Figure 4.5 Total Body BMC Means for Treatment Groups (subject set 4; n=28)
Figure 4.6 Femoral Neck BMD Means for Treatment Groups
(subject set 4; n=28)

- exercise/calculator
- exercise/placebo
- no exercise/calculator
- no exercise/placebo

Figure 4.7 Trochanter BMD Means for Treatment Groups
(subject set 4; n=28)

- exercise/calculator
- exercise/placebo
- no exercise/calculator
- no exercise/placebo

Study Measurement Time (months)
Figure 4.8 Lumbar Spine L2-L4 BMD Means for Treatment Groups (subject set 4; n=28)
Figure 4.9 Total Body BMC Change 0-6 Months and 6-18 Months (subject set 4, n=28)
In the matched blocks of subjects (subject set 4, n=28) a significant interaction for femoral neck BMAD was found between 0-6 months (P=0.07) (figure 4.10), indicating that calcium was beneficial in the no-exercise group but not in the exercise group. There was no significant interaction or main effects of calcium or exercise on femoral neck BMAD change in subject set 3 (n=50). There was a significant interaction at the lumbar spine for BMAD change between 0-6 months (P=0.09) in subject set 4 (n=28), but not in subject set 3. There was also a trend for a positive effect of calcium at the lumbar spine in subject set 4 (n=28) between 0-6 months. Subject set 3 demonstrated significant interactions for the lumbar spine, however, between 6-18 months (P=0.09, n=50) (figure 4.11) and 0-18 months (P=0.03, n=50) (table 4.23). Between 0-6 months and 6-18 months the interaction indicated that calcium was beneficial in the no-exercise group but not in the exercise group. Between 0-18 months the interaction indicated that exercise and calcium together had a negative effect on lumbar spine change.

In comparison to the results obtained for changes in areal bone mineral density at these sites, significance often occurred for the same effect during the same time period. However, significance was reached much more often in areal density changes than BMAD changes. Both areal density and BMAD showed significant change with time but not between the treatment groups with time. At the femoral neck both areal density and BMAD showed significant interaction 0-6 months in subject set 4 (n=28) but only areal density did for subject set 3 (n=50). At the lumbar spine only a trend for a main effect of calcium was found with BMAD whereas areal density changes, due to calcium effects, reached significance. A significant interaction between 0-6 months was noted for BMAD change but not areal density change in subject set 4, n=28. Between 6-18 months BMAD resulted in a significant interaction at the lumbar spine, whereas, areal
Figure 4.10 Femoral Neck BMAD Change: 0 to 6 Months
(significant interaction; $P=0.07$; subject set 4; $n=28$)

![Graph showing femoral neck BMAD change from 0 to 6 months with study groups and significant interaction](image1)

Study Group

Figure 4.11 Lumbar Spine L2-L4 BMAD Change: 6 to 18 Months (significant interaction; $P=0.09$; subject set 4; $n=50$)

![Graph showing lumbar spine L2-L4 BMAD change from 6 to 18 months with study groups and significant interaction](image2)

Study Group
density analysis did not reach significance. Both areal density and BMAD showed significant interactions at the lumbar spine in subject set 4 (n=28) 0-18 months. BMAD P values were generally higher than areal density P values for the same analyses, whether significance was reached or not.

**Total Calcium Intake and Bone Mineral Changes:**
Testing for a main effect of calcium on bone mineral changes by ANCOVA, as reported above, essentially tested the main effect of the intervention of calcium supplementation, and not the effect of the subjects' total calcium intake.

ANCOVA comparing subjects with low calcium intake (<600 mg/d) to subjects with high calcium intake (>1200 mg/d) to their bone mineral changes were thus completed to see if total calcium intake was a significant factor in bone mineral changes. Subject set 2 (n=87), all subjects who completed the study, was used for this analysis because of the greater number of subjects. Only six subjects were in the low intake group and 42 were in the high intake group. There was a significant difference between the high and low calcium intake subjects' bone mineral changes (greater in the high intake group) from 0-6 months for total body bone mineral content (P=0.004), total body bone mineral density (P=0.001), and lumbar spine bone mineral density (P=0.03), and from 0-18 months for total body bone mineral density (P=0.025). There was also a trend noted for increases in femoral neck bone mineral density (P=0.09) to be greater in the high calcium intake group between 0-18 months. These significant results disappeared if low calcium intake was considered to be <800 mg/d.

Correlation analyses were also completed to relate total calcium intake to bone mineral changes. These results are presented in table 4.26 and detailed in the correlation results section below. A significant correlation was noted only for
0-6 month bone density changes at the lumbar spine ($r=0.27$, $P=0.07$) and femoral neck ($r=0.32$, $P=0.02$) and from 0-18 months at the femoral neck ($r=0.31$, $P=0.03$). These results indicated that calcium only had an effect during the bone remodeling transient time of 0-6 months, and over the full duration of the study (18 months). To investigate the hypothesis of calcium being a threshold nutrient a scatter plot of total calcium intake and total body bone mineral density change from 0-18 months was done (figure 4.12). The scatter plot indicated a curvilinear relationship where bone mineral density changes increased with increasing calcium intake up until approximately 1200-1400 mg/d, then the curve of bone density change leveled off as calcium intake increased.

The estimated amount of calcium being retained per day between 6-18 months of the study, the true intervention period, was based on the amount of total body bone mineral content change during that time frame ($52 \text{ g} \pm 50 \text{ g}$, maximum was 150 g). An estimated mean of $44.8 \pm 44.3 \text{ mg}$ per day (range -66 to 135 g/d) was being retained by the subjects (subject set 3, n=50). This was then converted to a retention factor based on the subjects' mean daily total calcium intake. The mean estimated retention efficiency of calcium was $3.7 \pm 3.9\%$ (maximum was 14.6%).

A significant negative correlation of $-0.53$ ($P<0.000$) between maturation and calcium retention efficiency was found indicating that efficiency decreased the further past menarche the subjects were (figure 4.13). A correlation of 0.27 ($P=.05$) between total calcium intake and retention efficiency was found indicating that more calcium was retained the higher calcium intake. Calcium retention efficiency was also calculated for the four individual case study subjects, presented in the section below, who would have been between 2.5-3.5 years past menarche at the six-month point of the study, plus retention efficiency was calculated for four other subjects who were between seven and nine months
Figure 4.12 Suggestion of a Threshold Effect of Calcium (subject set 2, n=87)
Figure 4.13 Correlation Between Calcium Retention Efficiency and Maturation (subject set 3, n=50; r=0.55, P=0.00)
Table 4.24 Calcium Retention Efficiency of Case Studies

<table>
<thead>
<tr>
<th>variable:</th>
<th>maturation* at 6 mo. into study</th>
<th>bone mineral gained (g)</th>
<th>total calcium intake (mg/d)</th>
<th>calcium retained 6-18 mo. (mg/d)</th>
<th>calcium retention (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>subject:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>case study subjects - intervention</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 - exercise &amp; calcium</td>
<td>30</td>
<td>120</td>
<td>1108</td>
<td>106</td>
<td>10</td>
</tr>
<tr>
<td>2 - calcium only</td>
<td>42</td>
<td>50</td>
<td>1149</td>
<td>44</td>
<td>4</td>
</tr>
<tr>
<td>3 - exercise only</td>
<td>33</td>
<td>20</td>
<td>536</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>4 - control (no intervention)</td>
<td>44</td>
<td>40</td>
<td>485</td>
<td>35</td>
<td>7</td>
</tr>
</tbody>
</table>

low maturation status calcium retention case study subjects - intervention

5 - calcium only | 6 | 140 | 976 | 123 | 13 |
6 - control (no intervention) | 9 | 130 | 1117 | 115 | 10 |
7 - control (no intervention) | 9 | 90 | 936 | 79 | 9 |
8 - calcium only | 7 | 150 | 2151 | 132 | 6 |

* maturation was measured as months past menarche.

---

Table 4.25 Percent Changes in Case Studies

<table>
<thead>
<tr>
<th>subject # - intervention variable mean</th>
<th>1 - exercise &amp; calcium</th>
<th>2 - calcium only</th>
<th>3 - exercise only</th>
<th>4 - control (no intervention)</th>
</tr>
</thead>
<tbody>
<tr>
<td>dietary calcium (mg/d)</td>
<td>232</td>
<td>563</td>
<td>536</td>
<td>485</td>
</tr>
<tr>
<td>total calcium (mg/d)</td>
<td>1108</td>
<td>1149</td>
<td>536</td>
<td>485</td>
</tr>
<tr>
<td>exercise compliance (%)</td>
<td>73.1</td>
<td>N/A</td>
<td>73.1</td>
<td>N/A</td>
</tr>
<tr>
<td>maturation (mo.)</td>
<td>24</td>
<td>36</td>
<td>27</td>
<td>38</td>
</tr>
<tr>
<td>age (y)</td>
<td>15.6</td>
<td>16.9</td>
<td>16.5</td>
<td>13.6</td>
</tr>
<tr>
<td>0-6 month changes: (% change)</td>
<td>0.04</td>
<td>0.5</td>
<td>0.7</td>
<td>2.3</td>
</tr>
<tr>
<td>TBBMC</td>
<td>-1.6</td>
<td>-2.3</td>
<td>2</td>
<td>-6.6</td>
</tr>
<tr>
<td>TBBMD</td>
<td>1.1</td>
<td>2.7</td>
<td>2.3</td>
<td>3.3</td>
</tr>
<tr>
<td>FNBMD</td>
<td>5.9</td>
<td>4.7</td>
<td>0.5</td>
<td>-1.9</td>
</tr>
<tr>
<td>Troch. BMD</td>
<td>4.4</td>
<td>5.4</td>
<td>1.1</td>
<td>2</td>
</tr>
<tr>
<td>L2-L4 BMD</td>
<td>4.8</td>
<td>2.7</td>
<td>0.7</td>
<td>1.7</td>
</tr>
<tr>
<td>6-18 month changes: (% change)</td>
<td>4.8</td>
<td>2.7</td>
<td>0.7</td>
<td>1.7</td>
</tr>
<tr>
<td>TBBMC</td>
<td>2.9</td>
<td>-2.8</td>
<td>-1.6</td>
<td>0.3</td>
</tr>
<tr>
<td>TBBMD</td>
<td>1.4</td>
<td>-0.2</td>
<td>-3.7</td>
<td>-3.8</td>
</tr>
<tr>
<td>FNBMD</td>
<td>4.6</td>
<td>-0.3</td>
<td>-5.9</td>
<td>-1.8</td>
</tr>
<tr>
<td>Troch. BMD</td>
<td>4.4</td>
<td>-1.3</td>
<td>-1.6</td>
<td>3.9</td>
</tr>
<tr>
<td>L2-L4 BMD</td>
<td>4.9</td>
<td>3.3</td>
<td>1.4</td>
<td>4</td>
</tr>
<tr>
<td>0-18 month changes: (% change)</td>
<td>4.9</td>
<td>3.3</td>
<td>1.4</td>
<td>4</td>
</tr>
</tbody>
</table>

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185
postmenarche at the six-month point of the study (table 4.24). Subjects who were lower in maturational status had higher retention efficiency and thus were the ones who gained more grams of bone mineral between 6-18 months.

**Case Studies:**

Four case studies were compared to see if changes in the four different treatment groups followed the original hypothesis. The purpose of doing this was to try to eliminate some of the confounding variance in the entire data sets, which could possibly explain the limited effects of the intervention program being observed, and to determine whether the intervention program actually worked. Although a case study may show a pattern of change it only represents one example. Four subjects, one from each treatment group, having the lowest dietary calcium intake in their respective group as estimated from three-day diet records, and being at least two years past menarche at the start of the study, were chosen for the case studies (table 4.25). The higher maturation level was chosen since bone accretion rates are slower the further past menarche, thus variance in rate of accretion for similar maturation levels would be less (Bailey et al., 1997). The results of the case comparisons showed that between 6-18 months (the true intervention time considering the six-month transient period) the subject with both exercise and calcium supplementation intervention had the greatest changes in total body bone mineral content and density and density at the three other sites measured. The subject who received only the exercise intervention had the lowest changes in all the bone mineral measures, except total body bone mineral density, indicating that exercise had no positive effect when calcium intake was low. The subject who received calcium intervention had the second greatest changes in bone mineral. The subject that received no intervention had the second to least changes in bone mineral measures, except at the spine, where
this subject had the greatest change over the three other cases. This pattern followed the original hypotheses that the exercise and calcium, and calcium-only subjects would have the greatest increases in bone mineral. The pattern was quite similar for the changes seen between 0-18 months as well, plus, total body bone mineral density also followed the pattern with the exercise only subject having the least change, and the exercise and calcium intervention subject having the greatest change.

The changes between 0-6 months were viewed for possible evidence of the remodeling transient. The pattern was not quite as clear in the case studies during this time frame as in the 6-18 month period, especially in terms of the control subject. However, total body bone mineral density change was lower in the two exercising subjects, more so in the one not receiving calcium supplementation (-1.6% and -2.0% respectively), than the one who was receiving just calcium supplementation (2.3%). This pattern was similar for the spine as well (4.4% exercise and calcium, 1.1% exercise only, 5.4% calcium only). This pattern suggested that exercise increased remodeling and that calcium partly offset this by decreasing remodeling, therefore, the exercise only and calcium only subjects would demonstrate the two extremes in change (least and most change, respectively), which they did. This supports the remodeling hypothesis. At the femoral neck the greatest change was noted in the calcium only group (2.7%), which was consistent with changes at the other sites, but the exercise only subject followed next (2.3%) and then the exercise and calcium subject (1.1%). At the trochanter the subject participating in exercise and calcium supplementation had the greatest changes, followed by the calcium supplemented, the exercise only, and finally the control subject.
Correlation Analysis Results:
Subject set 3 (n=50) was used for correlation analyses to use all the subjects who completed and complied with the intervention program. Results of bivariate correlation analysis revealed that maturation and body weight change had strong associations with changes in bone mineral at most sites over most time periods. Total calcium intake and exercise compliance were also strong correlates for changes at some bone sites (table 4.26).

Between 0-6 months maturation (r=-0.31), total calcium intake (r=0.32) (figure 4.14) and exercise compliance (r=0.5) (figure 4.15) were all significantly (P< 0.03) associated with changes in femoral neck bone mineral density and all three factors together accounted for 36% of the variance. This was similar for the lumbar spine bone mineral density changes during the same time frame where maturation (r=-0.45), weight change (r=0.36), total calcium (r=0.27) (figure 4.16) and exercise compliance (figure 4.17) accounted for 38% of the variance. Only maturation and/or weight change were significant correlates to bone mineral changes between 6-18 months. For total body bone mineral content changes maturation (r=-0.59) and weight change (r=0.59) (figures 4.18 and 4.19, respectively) accounted for 56% of variance.

Between 0-18 months exercise compliance was the only significant (P=0.03) factor associated with total body bone mineral density changes accounting for 38% of the variance. This time period was the only time when a factor was significantly associated with trochanter bone mineral density changes. Total calcium contributed 12% of the variance (P=0.01) at this site. Again maturation and weight change were the most consistent factors associated with the bone
Table 4.26 Summary of Significant Factors Correlating to Bone Mineral Changes (subject set 3, n=50)

<table>
<thead>
<tr>
<th>variables: factors:</th>
<th>0-6 month changes</th>
<th>6-18 month changes</th>
<th>0-18 month changes</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>R squared</td>
<td>P value</td>
</tr>
<tr>
<td>TBBMD maturation</td>
<td>-0.44</td>
<td>0.19</td>
<td>0.01</td>
</tr>
<tr>
<td>exercise compliance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBBMC weight change</td>
<td>0.57</td>
<td>0.32</td>
<td>0.00</td>
</tr>
<tr>
<td>maturation</td>
<td>-0.65</td>
<td>0.43</td>
<td>0.00</td>
</tr>
<tr>
<td>both together</td>
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<td></td>
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<tr>
<td>accounted for 56% of variance</td>
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</tr>
<tr>
<td>accounted for 56% of variance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>accounted for 60% of variance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FNBMD exercise compliance</td>
<td>*0.50</td>
<td>0.25</td>
<td>0.03</td>
</tr>
<tr>
<td>total calcium</td>
<td>*0.32</td>
<td>0.10</td>
<td>0.02</td>
</tr>
<tr>
<td>maturation</td>
<td>-0.31</td>
<td>0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>weight change</td>
<td>0.31</td>
<td>0.10</td>
<td>0.03</td>
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<tr>
<td>all 3 together</td>
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<tr>
<td>accounted for 36% of variance</td>
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<tr>
<td>accounted for 32% of variance</td>
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<tr>
<td>Troch. BMD total calcium</td>
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<td></td>
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</tr>
<tr>
<td>L2-L4 BMD maturation</td>
<td>-0.45</td>
<td>0.20</td>
<td>0.00</td>
</tr>
<tr>
<td>weight change</td>
<td>0.36</td>
<td>0.13</td>
<td>0.01</td>
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<td>*0.27</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>exercise compliance</td>
<td>*0.48</td>
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<td>all together</td>
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<tr>
<td>accounted for 38% of variance</td>
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<td></td>
</tr>
<tr>
<td>accounted for 41% of variance</td>
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</tr>
</tbody>
</table>

* indicate correlations which have been plotted in figures 4.14 - 4.19.
Figure 4.14 Correlation Between Total Calcium Intake and Femoral Neck BMD Change 0-6 Months (subject set 3, n=50; r=0.32, P=0.02)
Figure 4.15 Correlation Between Exercise Compliance and Femoral Neck BMD Change 0-6 Months (subject set 3, n=18 exercise subjects; $r=0.5$, $P=0.03$)
Figure 4.16 Correlation Between Total Calcium Intake and Lumbar Spine
L2-L4 BMD Change 0-6 Months (subject set 3, n=50; r=0.27, P= 0.05)
Figure 4.17 Correlation Between Exercise Compliance and Lumbar Spine
L2-L4 BMD Change 0-6 Months (subject set 3, n=18 exercise subjects; r=0.48, P=0.04)
Figure 4.18 Correlation Between Maturation and Total Body BMC Change

6-18 Months (subject set 3, n=50, r=0.59, P<0.00)
Figure 4.19  Correlation Between Change in Body Weight and Total Body BMC Change 6-18 Months (subject set 3, n=50; r=0.59, P=0.00)
mineral changes and together accounted for 41% of the variance of lumbar spine changes and 60% of the variance in total body bone mineral density changes.

Changes in upper and lower body strength and lean mass were also tested for significant associations with changes in bone mineral (table 4.27). Although repeated measures ANCOVA indicated that changes in lean mass between the four treatment groups did not differ across time, but lean mass across time did change significantly ($P=0.007$), changes in lean mass correlated significantly to changes in total body bone mineral content and bone mineral density many of the bone sites measured. Between 0-6 months lean mass change correlated significantly with changes in density at the trochanter ($r=0.3$, $P=0.02$), femoral neck ($r=0.3$, $P=0.02$), and total body bone mineral content ($r=0.3$, $P=0.02$). Between 6-18 months the only significant correlation with lean mass change was that of total body bone mineral content change ($r=-0.3$, $P=0.04$). Between 0-18 months lean mass change significantly correlated with changes in lumbar spine ($r=0.3$, $P=0.02$) and trochanter bone mineral density ($r=0.4$, $P=0.004$), and total body bone mineral content ($r=0.3$, $P=0.03$). Change in strength, specifically the upper body, was significantly correlated only to change in total body bone mineral density from 0-18 months and the correlation was negative ($r=-0.41$, $P<0.01$). For most results, weight change had higher correlations with changes in bone mineral changes than did strength or lean body mass changes. There were no significant correlations observed between exercise compliance, lean mass changes and strength changes.

**Skeletal Area and Bone Size Changes:**
Repeated measures ANCOVA on subject set 3 ($n=50$) and subject set 4 ($n=28$) indicated that skeletal area for total body ($P=0.00$) and trochanter ($P=0.001$) had
<table>
<thead>
<tr>
<th>variable: factors:</th>
<th>0-6 month changes</th>
<th>6-18 month changes</th>
<th>0-18 month changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>R squared</td>
<td>P value</td>
</tr>
<tr>
<td>TBBMD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>upper body strength*</td>
<td>-0.41</td>
<td>0.17</td>
<td>0.01</td>
</tr>
<tr>
<td>TBBMC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lean mass</td>
<td>0.30</td>
<td>0.09</td>
<td>0.03</td>
</tr>
<tr>
<td>FNBMD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lean mass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Troch. BMD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lean mass</td>
<td>0.40</td>
<td>0.16</td>
<td>0.04</td>
</tr>
<tr>
<td>L2-L4 BMD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lean mass</td>
<td>0.33</td>
<td>0.11</td>
<td>0.02</td>
</tr>
</tbody>
</table>

* upper body strength was measured by bench press 1RM.
significant changes across time yet there were no differences in area changes between the groups across time. A trend was noted, however, for differences in total body area ($P=0.09$) between groups across time in subject set 3 ($n=50$) only. Table 4.28 presents the changes in skeletal area.

In subject set 4 ($n=28$), ANCOVA, with weight change as the covariate, indicated a significant interaction between 0-6 months ($P=0.09$) (figure 4.20) indicating that exercise and calcium together promoted greater increases in area than either factor alone, however, the no-exercise/placebo group showed the greatest changes of the four different treatment groups (table 4.29). There were no significant interactions between calcium and exercise in subject set 3 ($n=50$). For femoral neck area there was a trend for a positive main effect of exercise and a negative main effect of exercise at the trochanter between 0-6 months ($P=0.07$ and $P=0.06$, respectively). Subject set 3 revealed a significant negative effect of exercise for trochanter area ($P=-0.02$). A trend for a negative main effect of exercise was also found for lumbar spine area between 0-6 months ($P=0.1$) and in subject set 3, for total body bone area ($P=0.05$). A trend for a positive main effect of calcium was noted only for lumbar spine area between 0-6 months ($P=0.1$) in subject set 4 ($n=28$).

The only significant effect during the 6-18 month intervention period was a negative one of calcium on lumbar spine skeletal area ($P=-0.05$, $n=28$). Between 0-18 months a trend of a negative effect of exercise on total body ($P=-0.1$, $n=28$) and lumbar spine ($P=-0.7$, $n=50$) skeletal area were observed. There was also a significant interaction ($P=0.06$, $n=28$) for total body skeletal area indicating that exercise and calcium together promoted greater increases in area than either
Table 4.28: Skeletal Area Changes (cm²) (subject set 3, n=50; subject set 4, n=28)

<table>
<thead>
<tr>
<th>variable mean (SD) cm²</th>
<th>total body skeletal area</th>
<th>femoral neck area</th>
<th>trochanter area</th>
<th>Lumbar Spine L2-L4 area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.6 month changes:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>change</td>
<td>% change</td>
<td>change</td>
<td>% change</td>
</tr>
<tr>
<td>whole group</td>
<td>114.81 (69.8)</td>
<td>4.5</td>
<td>93.89 (60.6)</td>
<td>3.7</td>
</tr>
<tr>
<td>exercise/calcium</td>
<td>85.76 (35.8)</td>
<td>3.2</td>
<td>94.11 (36.4)</td>
<td>3.7</td>
</tr>
<tr>
<td>exercise/placebo</td>
<td>79.23 (40.9)</td>
<td>3.1</td>
<td>78.46 (44.8)</td>
<td>3.1</td>
</tr>
<tr>
<td>no exercise/calcium</td>
<td>117.58 (84.7)</td>
<td>4.7</td>
<td>64.74 (72.5)</td>
<td>2.6</td>
</tr>
<tr>
<td>no exercise/placebo</td>
<td>148.4 (68.7)</td>
<td>5.5</td>
<td>132.72 (87.3)</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>0.8 month changes:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>change</td>
<td>% change</td>
<td>change</td>
<td>% change</td>
</tr>
<tr>
<td>whole group</td>
<td>24.51 (41.3)</td>
<td>0.9</td>
<td>32.62 (41.2)</td>
<td>1.2</td>
</tr>
<tr>
<td>exercise/calcium</td>
<td>20.14 (33.3)</td>
<td>0.7</td>
<td>27.76 (30.6)</td>
<td>1.1</td>
</tr>
<tr>
<td>exercise/placebo</td>
<td>14.57 (47.3)</td>
<td>0.6</td>
<td>21.27 (48.3)</td>
<td>0.8</td>
</tr>
<tr>
<td>no exercise/calcium</td>
<td>22.71 (47.9)</td>
<td>0.9</td>
<td>34.00 (60.0)</td>
<td>1.3</td>
</tr>
<tr>
<td>no exercise/placebo</td>
<td>34.34 (36.3)</td>
<td>1.3</td>
<td>45.64 (23.9)</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>0.18 month changes:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>change</td>
<td>% change</td>
<td>change</td>
<td>% change</td>
</tr>
<tr>
<td>whole group</td>
<td>39.32 (74.1)</td>
<td>5.6</td>
<td>126.51 (60.7)</td>
<td>4.9</td>
</tr>
<tr>
<td>exercise/calcium</td>
<td>105.00 (55.0)</td>
<td>3.9</td>
<td>121.87 (48.2)</td>
<td>4.8</td>
</tr>
<tr>
<td>exercise/placebo</td>
<td>93.80 (55.4)</td>
<td>3.7</td>
<td>99.72 (51.7)</td>
<td>3.9</td>
</tr>
<tr>
<td>no exercise/calcium</td>
<td>40.29 (76.4)</td>
<td>5.6</td>
<td>98.74 (32.6)</td>
<td>3.9</td>
</tr>
<tr>
<td>no exercise/placebo</td>
<td>182.74 (70.2)</td>
<td>7.2</td>
<td>78.36 (70.6)</td>
<td>6.9</td>
</tr>
</tbody>
</table>
Figure 4.20 Total Body Bone Mineral Area Change: 0 to 6 Months (significant interaction; P=0.09; subject set 4; n=28)

![Bar chart showing total body bone mineral area change over 0 to 6 months with different study groups indicated]

Table 4.29 Summary of P values for Interactions and Main Effects of Exercise and Calcium Supplementation on Skeletal Area and Bone Size Changes (subject set 3, n=50, subject set 4, n=28)

<table>
<thead>
<tr>
<th>Study Group</th>
<th>Total Body Skeletal Area</th>
<th>Femoral Neck Skeletal Area</th>
<th>Trochanter Skeletal Area</th>
<th>Lumbar Spine L2-L4 Skeletal Area</th>
<th>Bicristal Bone Breadth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-6 months</td>
<td>0-18 months</td>
<td>0-6 months</td>
<td>0-18 months</td>
<td>0-18 months</td>
</tr>
<tr>
<td>exercise</td>
<td>(-)0.05*</td>
<td>(-)0.01*</td>
<td>(-)0.06</td>
<td>(-)0.02*</td>
<td>0.07</td>
</tr>
<tr>
<td>calcium</td>
<td>n=28</td>
<td>n=28</td>
<td>n=50</td>
<td>n=50</td>
<td>n=50</td>
</tr>
<tr>
<td>placebo</td>
<td>n=50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>interaction</td>
<td>0.09*</td>
<td>0.06*</td>
<td></td>
<td></td>
<td>0.05*</td>
</tr>
</tbody>
</table>

Only significant changes, indicated by *, and trends are presented. Main effects of calcium and exercise were positive unless indicated by a "(-)". All effects were controlled for changes in body weight. Significant interactions indicated that the effects of calcium varied with exercise e.g., the exercise and calcium group had smaller changes than the calcium group but greater changes than the exercise group.
factor alone, however, the no-exercise/placebo group had the greatest increases.

Repeated measures ANCOVA, with weight as the covariate, for changes in bone size for subject set 3 (n=50) and 4 (n=28) indicated that all six bone breadth measures significantly changed across time (P<0.001), but there was no significant differences between the four treatment groups across time, except for the bicristal breadth in subject set 4 (n=28) (P=0.05). ANCOVA, to test for main effects of an interaction, calcium and weight training from 0-18 months on bone size changes, revealed a significant effect of an interaction at the bicristal bone breadth (P=0.05) (subject set 4, n=28), indicating that exercise and calcium together was more beneficial to change in breadth than either factor on its own. A positive effect of exercise on bicristal bone breadth was noted (P=0.05) in subject set 3 (n=50), but only a trend was noted in subject set 4 (n=28) (P=0.07) (table 4.29).

**Program Compliance Factors:**

The program questionnaire completed by all 87 subjects at the end of the study asked questions relating to factors which either helped or hindered their compliance with the components of the program. The factors included in the questionnaire were based on those identified through the PRECEDE PROCEED model while planning the intervention program as well as from observations made throughout the course of the study. Although the questionnaire was designed specifically for this study, and not tested for reliability or validity beforehand, it was set up in the format of five-point rating scales which have been widely used and validated in other research. A "5" on the scale would indicate that a factor was a major influence on compliance whereas a "1"
indicated a factor which was a major hindrance to compliance. The questionnaire was also completed during the last testing session so the author could explain clearly how to complete the questionnaire.

The questionnaire consisted of four questions representing each component of the study intervention: a) initial motivation to volunteer for the study, b) calcium/placebo-supplementation compliance, c) record-keeping compliance, and d) weight-training compliance. Open-ended questions about what they liked least and most about being in the study, and the most important thing subjects learned from participating were also asked. The means, standard deviations, and rankings of all factors are recorded in appendix M - b but the main results are described below.

The factors affecting subjects' initial decision to volunteer for the study which had the highest mean (indicating most influential), were that the program sounded interesting and fun (mean = 3.6), and it was an opportunity to participate in and learn about weight-training (mean = 3.5).

The factors which contributed mostly to compliance with the calcium/placebo supplementation were the belief that calcium would help their bones (mean = 4.1), reminders from the author to take their supplements (mean = 3.9), and a feeling of obligation to the study (mean = 3.8). The factors which hindered subjects' compliance the most were forgetting to take them (mean = 2.1), thinking that they had the placebo, and the large size of the tablet (mean = 2.7). Some of these factors were also important for compliance with the task of record keeping (e.g., physical activity, calcium/placebo taking and menstrual records). Reminders from the author to do them (mean = 3.9), and a feeling of obligation
to the study (mean = 3.8) were the second and third most influential factors, respectively, and having the bone scan and nutritional analysis done was the first (mean = 4.1). Forgetfulness (mean = 2.0) and the time-consuming process of keeping the records (mean = 2.3) were indicated as the most hindering factors for compliance, as indicated by the ranking of means.

For compliance with the weight-training component of the program, the factors influencing higher compliance were the desire of the subjects to become stronger, more toned (mean = 4.4), and to enhance sport performance (mean = 4.1), knowledge of the benefits of exercise (mean = 4.3), encouragement from the author and training assistants (mean = 3.9), and trying a new challenge or goal (mean = 3.88). The main hindering factors for compliance were that the program was time consuming (mean = 1.6), and other school commitments (mean = 2.0) and family or extra-curricular obligations took priority (mean = 2.2). The fourth ranked hindering factor was the atmosphere in the weight room (mean = 2.7), despite the efforts to make it a bright, clean, educational, and motivational setting.

The responses to the open-ended questions about what was liked least and most about the program further confirmed the results of the 5-point scale questions about factors affecting compliance. Keeping all the records, taking the pills, length and time consuming program were consistently reported as the least liked aspects of the program. Aspects of the program which were highly reported as being liked the most were learning more about the body, bones, health, osteoporosis and actually getting the bone scan and nutritional analysis results, the social aspects (meeting new people, social get-togethers, being part of
an important study), getting stronger and seeing the aesthetic changes over the 18 months, and learning more about proper weight training.

The responses to the question regarding the most important thing learned through participation in the study largely focused around aspects of the importance of healthful eating and exercise, osteoporosis prevention, how to train with weights properly, and responsibility and dedication. This question helps evaluate the impact of the program, as outlined in the PRECEDE PROCEED model with the idea that the learning will lead to change in health behaviors.

4.5 Summary of Results

The significant results are summarized under the headings of the stated hypotheses for the research indicating evidence either supporting or refuting each hypothesis.

General Hypothesis:

Increases in bone mineral content, density and skeletal area and bone size will be greater in those subjects who participated in the progressive weight-training and calcium-supplementation program than in the non-exercising and control subjects.

Supportive Evidence:
- none
Negative Evidence:
- there were no significant differences between the four treatment groups on any of the dependent bone mineral and size variables observed

Conclusion:
- hypothesis rejected

Specific Hypotheses:
1. Between months 6-18 of the intervention, subjects participating in the weight-training program will have greater increases in bone mineral content and density, skeletal area and bone size than those in the non-exercise group.

Supportive Evidence:
- none

Negative Evidence:
- no positive effects of weight training for any bone mineral or size measure
- no group effect indicating significant differences between the changes observed in each of the four treatment groups
- negative effect of weight training for lumbar spine bone mineral density (n=28)
- exercise compliance was not associated with changes in bone mineral (n=50)

Conclusion:
- hypothesis rejected
2. Between months 6-18 of the intervention, subjects receiving the calcium supplementation will have greater increases in bone mineral content and density, skeletal area and bone size than those receiving placebo.

Supportive Evidence:
- interactions indicated that calcium was beneficial to femoral neck bone mineral density in the weight-training group

Negative Evidence:
- no positive effects of calcium supplementation on bone mineral or bone size at any site
- no positive correlations of total calcium intake with bone mineral or bone size changes at any site
- negative effect of calcium supplementation on lumbar spine bone mineral density (n=28)
- negative effect of calcium supplementation on lumbar spine area (n=28)

Conclusion:
- hypothesis rejected

3. Over the 18 month intervention the effects of weight training and calcium supplementation will interact, and the increases in bone mineral and skeletal area in the calcium-supplemented weight-training group will be greater than those in the calcium-supplemented or weight-training only groups, and control group.
Supportive Evidence:

- interaction between the four treatment groups across the duration of the study for femoral neck, lumbar spine, and trochanter bone mineral density changes indicated that one or more groups were changing at a different rate than the other treatment groups due to the intervention (n=28)
- interaction for femoral neck bone mineral density indicated that calcium supplementation was beneficial in the weight-training group but not in the non weight-training group (n=28, 6-18 months)
- interaction for total body bone mineral content (n=87) and for lumbar spine bone mineral density (n=28) indicated that calcium supplementation was beneficial in the weight-training group but not in the non weight-training group (0-6 months)
- interaction for total body skeletal area indicated that calcium supplementation was beneficial in the weight training group but not in the non-weight training group (n=28, 0-6 months)

Negative Evidence:

- interaction for femoral neck bone mineral density indicated benefits of calcium supplementation in the non weight-training group but not in the weight-training group (n=28 and n=50, 0-6 months)
- interaction for lumbar spine bone mineral density indicated benefits of calcium supplementation in the non weight-training group but not in the weight-training group (n=50, 6-18 months)
- only one positive significant interaction during the true intervention period of 6-18 months for bone mineral density, content and size was observed
Conclusion:
- hypothesis accepted

4. Factors relating to program convenience, time commitment and enjoyment will have the greatest impact on program compliance.

Supportive Evidence:
- time commitment, social and perceived health, fitness and aesthetic benefits were the factors rated as having the most impact on program compliance

Negative Evidence:
- none

Conclusion:
- hypothesis accepted

5. A bone remodeling transient will be evident between 0-6 months of the intervention in the weight-training and/or calcium-supplementation groups, indicated by greater increases in bone mineral and skeletal area in the calcium-supplemented groups and smaller increases, or decreases, in bone mineral and skeletal area in the weight-training groups.

Supportive Evidence:
- interaction for lumbar spine bone mineral density indicated that calcium supplementation was beneficial in the weight-training group but not in the non weight-training group (n=28)
interaction for total body skeletal area indicated that calcium supplementation was beneficial in the weight-training group but not in the non-weight training group (n=28)
- positive effect of calcium supplementation for lumbar spine bone mineral density (n=28)
- total calcium intake was positively correlated with femoral neck and lumbar spine bone mineral density (n=50)
- those subjects with high total calcium intake had greater increases in total body bone mineral density and content and lumbar spine bone mineral density
- negative effect of weight training for total body and trochanter skeletal area (n=50)

Negative Evidence:
- interaction for femoral neck bone mineral density indicated benefits of calcium supplementation for the non weight-training group but not for the weight-training group (n=28 and n=50)
- exercise compliance was positively correlated with femoral neck and lumbar spine bone mineral density (n=50)

Conclusion:
- hypothesis accepted

Other Significant Results:
- maturation, weight change and change in lean body mass were associated with changes in most bone mineral measures
- BMAD resulted in higher P values than areal density results but significance in changes occurred at the same sites, for the most part.
- A negative association was found between maturation and calcium retention efficiency.
- Plot of calcium intake against change in total body bone mineral density suggested a threshold effect of calcium.
- Between 0-18 months:
  
i) Body weight, height, percent body fat and all bone mineral and size measures all changed across the duration of the study.
  
ii) Lower body strength and bicristal bone breadth increased more in the weight-training group than in the non weight-training group.
  
iii) Positive effect of weight training on trochanter bone mineral density (n=28).
  
iv) Weight-training compliance was positively related with total body bone mineral density (n=50).
  
v) Positive effect of weight training on bicristal bone breadth (n=50).
  
vi) Weight training had a negative effect on total body (n=50) and lumbar spine skeletal area (n=28).
  
vii) Positive effect of calcium supplementation on trochanter bone mineral density (n=87 and n=50).
  
viii) Total calcium intake was positively related to femoral neck bone mineral density.
  
ix) High total calcium intake (>1200 mg/d), as opposed to low intake (<600 mg/d), was positively associated with total bone mineral density.
  
x) Interaction for total body skeletal area and for bicristal bone breadth indicated that calcium supplementation was beneficial in
the weight training group and not the non-weight training group (n=28)

xi) interaction for lumbar spine bone mineral density indicated benefits of calcium supplementation in the non weight-training group but not in the weight-training group (n=50)

xii) interactions for total body skeletal area and bicristal bone breadth indicated that the weight-training and calcium-supplementation group had smaller changes than calcium supplementation alone (n=50)
Chapter 5. Discussion

This was a 2x2 quasi-experimental study investigating the effects of 18 months of weight training and calcium supplementation on bone mineral in adolescent girls. Its purpose was to see if bone mineral could be augmented beyond the normal increase observed due to growth during this time, with the long-term goal of osteoporosis prevention. Although the results do not simply and clearly agree or disagree with the hypothesis stated, that the weight-training and calcium-supplemented subjects would have greater gains in bone mineral, interpretation of the results reveals valuable and practical implications for understanding bone mineral changes during adolescence.

5.1 Baseline Descriptives

The subjects were within the normal ranges for their age on growth parameters such as height, weight, maturation, and percent fat (Malina and Bouchard, 1991). Total body bone mineral and site-specific bone mineral densities were very similar to other data sets of adolescents (Faulkner et al., 1993 and 1996; Kroger et al., 1992; Plotkin et al., 1996; Zanchetta et al., 1995).

5.2 Program Compliance and Factors Affecting Compliance

Nineteen percent of the subjects did not complete the study but the drop-out rate is better described as 54% once the subjects who did not have at least 50% compliance with the program are considered. This drop-out figure is comparable to that often observed in adults within the first six months of starting an exercise program (Dishman, 1988). The overall compliance rate in this study was much lower than the rates observed in training studies in the elderly, for example 75-102% (Gleeson et al., 1990; Pruitt et al., 1995) but this may be due to the fact that for the elderly, involvement in a study was probably
a focal point in their life at that time, whereas adolescent girls have many other commitments and interests which could reduce their compliance, as indicated by the results of the program questionnaire in that other school commitments were a major inhibitor to participation. In comparison to young-adult training studies, where compliance as high as 92% has been reported (Gleeson et al., 1990; Snow-Harter et al., 1992; ), subjects' compliance in this present study was lower. The only other weight-training study investigating bone mineral changes in adolescent girls (Blimkie et al., 1996) reported that half the subjects had a compliance rate of at least 80% and the remaining half had compliance rates ranging between 50-80% which is closer to the results of this study. However, their study was only one third the length of this one. Friedlander et al. (1995) investigated 20-35 year olds involved in a two-year weight-training and aerobics program and reported a mean compliance of 61%, with higher attendance in the first six months of the study and lower in the last six months of the study. This was a similar pattern observed in the adolescent girls participating in this present study.

The reason often stated by adults for starting an exercise program or making any effort to change health behaviors is knowledge of health risk or a perceived susceptibility to a health problem (Green and Kreuter, 1991). In the case of the adolescents in this study, the primary reason for participating was because the program sounded interesting and fun. As indicated by the final program questionnaire results, the social and fun aspects were important for continuation in the program, but also the increased awareness of the importance of physical activity and nutrition, and having the bone scans and nutritional analyses done were main reasons stated for facilitating compliance. These results seem almost opposite to adults who start exercising for health reasons and continue for fun
and social reasons. Adolescents seemed to start for fun and social reasons and continue for social, fun and the perceived health and aesthetic benefits. This is in agreement with the fact that when knowledge level is low, new knowledge may be a crucial predisposing factor for participation (Brouchard, 1991; Dishman, 1991 and 1994). Osteoporosis, being a disease which primarily manifests in later years, is something few adolescents would feel they were susceptible to, and belief in susceptibility is the first criterion in the health belief model necessary for health behaviour change to occur. This could be the reason why it was not a factor for initial participation for the adolescents in this study, but did become a factor later as their knowledge and awareness increased. The increased knowledge and awareness of osteoporosis, health, and physical activity also emphasized that school age is an excellent time to intervene when lifestyle habits are being formed from the influence of significant others (Dishman, 1988; Ferguson et al., 1989).

The numerous incentives, i.e., T-shirts, prizes, motivational notice board, healthy snacks and refreshments, were not rated as main factors affecting compliance. The reason for this could have been that the prizes and other components of the incentive program were incorporated into the social get-togethers or weight-room atmosphere, and could have been interpreted as being part of the social aspect of the program. The social aspect was rated as a major factor affecting compliance. The use of these specific incentives may have different effects in different school socioeconomic-status situations, but the planning model used facilitated choice of appropriate incentives for this study. The fact that the program questionnaire was not tested for validity or reliability poses some limitations for the interpretation of these results. The fact that all exercise subjects were at one school may have affected or biased compliance results as
well, as opposed to if subjects had been randomized at all four participating schools into exercise and control groups.

Time and pressure from school commitments were indicated as the biggest inhibitors to compliance with the program which is in agreement with most other compliance research on adolescents (Dishman, 1991; Health and Welfare Canada, 1993; Naylor, 1992; Stephens and Craig, 1990). The intervention program was designed using the PRECEDE PROCEED model of health promotion program planning and evaluation to address factors of importance for adolescents and high bone mass, provide convenient facilities, skills teaching, good leadership, social aspects and a flexible program, as well as to address the policies and regulations involved in implementing a program in a school setting. That these factors were not stated as barriers to exercise, and the schools accepted and supported the program, implied success of the program planning and program format (Dishman, 1991; Green and Kreuter, 1991; Health and Welfare Canada, 1993; Naylor, 1992; Wankel, 1985a). Those barriers identified in this study, and the successful use of the PRECEDE PROCEED model should guide future programs in improving upon the low compliance rates, as well as implementation of school health education programs.

5.3 Bone Mineral Changes

In subject set 1 comprising the 87 subjects who completed the study, results indicated a significant interaction for one bone mineral measure and a significant effect of calcium for one bone mineral measure during two time periods of interest, 0-6 and 6-18 months. Only one of these results, that of a main effect of calcium, remained when the revised subjects sets were analyzed, but other significant effects became evident. Significant differences and effects were not
necessarily expected to be seen in the group of 87 subjects because it was confounded by the low and non-complying subjects. Analyzing this group is testing the effects of "intent to treat" as opposed to testing the actual effects of the intervention program which was the aim of the study. This was the reason revised subject sets were formed for analyses. Maintaining the matched blocking format in subject set 4 (n=28) was important for decreasing variance amongst subjects as much as possible to more clearly see the effects of intervention. The set of 50 subjects used the maximal number of subjects who completed and complied with the program. A higher number of subjects generally increases power and decreases the chance of type II errors. This was important for this study because with the multiple comparisons (three testing sessions, three time periods, and five bone mineral measures, two subject sets) the chance of type II errors increases (Colton, 1974). The method of analysis used for this study, repeated measures ANCOVA, partially compensated for this problem (Colton, 1974; Schutz, 1989). Directional hypotheses were stated because it was anticipated that the calcium-supplementation and exercise program would have positive effects on adolescent bone, as indicated by some evidence in the review of literature. Since previous research had not, however, clearly indicated positive effects, nor had any investigated the effects of interaction or the remodeling transient in adolescents, where the effect could be negative, two-tailed analyses were used. This made the analyses more rigorous in the sense that it decreased the chance of type II errors.

Analysis of the revised subject sets indicated significant changes with time for most bone measures which was expected because subjects were growing. However, differences in bone mineral changes between the treatment groups were not as clear as expected or as stated in the hypotheses. There are a number
of reasons to explain this, however. Some significant interactions and main
effects of calcium and/or exercise were observed which indicated that the
intervention did have some effect. Although subjects in set 4 (n=28) were
matched for maturation and body weight, the wide variation in bone mineral
accrual rates for similar maturational stages (Bailey et al., 1997; Martin et al.,
1997) is probably still large enough that any effects on bone mineral change due
to intervention may fail to show. In subject set 3 (n=50), although the subject
number was greater, the subjects were not matched for maturation or body
weight so the wide variance in subject characteristics could overshadow any
effect of the intervention program.

Bailey et al. (1997) indicated a strong association between maturation and bone
mineral accrual in that the timing of peak bone mineral accrual corresponded
closely with the timing of menarche. The results reported here substantiated this
with a strong negative correlation result between maturation and bone mineral
change (r=-0.59, P=0.00). Martin et al. (1997) plotted the curve of bone mineral
content velocity based on a cross-section of girls involved in the Saskatchewan
Pediatric Bone Mineral Study. They reported that individual velocities were
greater than the group means thus indicating a flattening effect by using cross-
sectional data. The implications for this study are that bone mineral growth
velocity curves will be steeper and narrower for the longitudinal data, indicating
greater variation in subjects' accrual rates even for the same maturational stage.
Therefore, large changes in bone mineral due to the intervention would need to
occur to result in statistically significant effects of calcium supplementation or
exercise. To illustrate the wide variation in the subject data and the impact of
maturation on variance, bone mineral content change between 6-18 months in
subject set 3 (n=50) was plotted against maturation (figure 5.1).
Figure 5.1 Variation in Subjects: Total Body BMC Change 6-18 Months Plotted Against Maturation (subject set 3, n=50)

* subjects with very low change were more mature (further past menarche) and had no height increase.
* subjects with very large changes were less mature (closer to just past menarche) and had greater increases in height.
The subjects who demonstrated the extremes in variance of bone mineral change in the plot had either a very high or low maturational status which would thus greatly affect their rate of bone mineral accrual, no matter which treatment group they were in. Figure 5.2 plots bone mineral growth velocity curves for bone mineral content for boys and girls five years before and after peak bone mineral content velocity (Martin et al., 1997) which clearly indicates the reduction in accrual past this peak velocity point. Accrual in our subjects would be greatly decreasing as well since the average maturational status was close to two years postmenarche. The peak velocity occurs at about the same time as menarche (Bailey et al., 1997). The actual amount of total body bone mineral accrual was 42 grams (n=28) over the year intervention which is lower than the 75 grams depicted in figure 5.2 at approximately three years postmenarche. Three of the four case studies also had lower gain than that shown in figure 5.2 (20, 40, 50 and 120 g vs. 75 g).

Figure 5.2 Bone Mineral Content Growth and Growth Velocity 5y Before and After Peak Bone Mineral Content Velocity (Martin et al., 1997)
The percent changes in the four different treatment groups for each bone mineral measure, as well as the plots of the mean values for each treatment group, for each bone mineral measure, from baseline to 6 months to 18 months (figures 4.4 - 4.8, subject set 4, n=28), indicate the direction of influence of the effects of the different treatments. Though there were no significant differences between groups there were significant interactions and main effects. The interaction between the groups across time at the lumbar spine, femoral neck and trochanter, plotted in figures 4.1-4.3, also indicated that the groups were changing differently at those sites across time due to the intervention.

The results of the changes in bone mineral, skeletal area and bone size are discussed in the two time frames being investigated, i.e., 6-18 months, the true intervention period, and 0-6 months the remodeling transient period. Data for 0-18 months was presented in the results section for the purpose of observing the changes in bone as though the remodeling transient was not considered. This may help explain the differences in results between this study and previous reported interventions.

The Bone Remodeling Transient; 0-6 Months:
During bone remodeling some bone remodeling units are activated, therefore, there are cavities on the surface of the bone in various stages of resorption and formation. Under equilibrium conditions, where there is no net gain or loss of skeletal mass after a remodeling cycle, the sum of all the cavities after resorption is called the bone remodeling space or volume. Under the influence of an intervention, such as exercise, more bone remodeling units are activated, therefore, more cavities in the bone surface are being eroded and this results in an increase in the remodeling space. Any bone measurement taken in the short
term of introduction of the exercise intervention will, therefore, show a decrease in bone mass. Over the long term, however, if the effects of exercise are positive, where more bone is deposited than eroded resulting in a net gain in bone mass, the true effects can be measured. Heaney (1994) and Frost (1963) have both argued that to measure a true effect of an intervention the baseline measure must be delayed until the transient is complete. The transient period is thought to be about one year in adults but much shorter, approximately six months, in adolescents (Heaney, 1994).

In the case of calcium supplementation as an intervention, it increases serum calcium and decreases parathyroid hormone (PTH) which results in reduced activation of bone remodeling units. This is an opposite effect to exercise. Therefore, bone remodeling space is reduced with calcium supplementation during the transient so short-term studies of calcium supplementation could show an increase in bone mass which would be the result of an artifact of the remodeling transient. On the basis of this explanation, the expectation would be that between 0-6 months calcium would increase bone mineral and exercise would decrease bone mineral. If calcium intake is low, PTH increases which increases the remodeling units activated as well as the depth of the resorption cavity. This can result in substantial bone loss if formation does not keep up. This is what happens during menopause or amenorrhea, two situations when there is little estrogen circulating to blunt the effects of PTH. The subjects in this study all had regular menstrual cycles (13-17 cycles) throughout the duration of the study, and none of them smoked, so situations of estrogen withdrawal did not confound results. Since use of oral contraceptives was an exclusion criterion, any possible effects they may have had did not confound the results.
Figures 5.3 and 5.4 show the changes in body composition and total body bone mineral and area during the remodeling transient period. Body composition changes need to be viewed along with bone mineral and area changes to better interpret the results. The pattern of results followed the expectations during the transient time as described above, especially for the effects of calcium. With height and/or weight gain, gain in total body bone mineral content is expected. Almost all subjects gained height. The no-exercise/placebo group gained the most weight, lean mass and percent body fat, but not the most bone mineral content, once adjusted for weight. The groups with supplemented calcium had the greatest increases in total body bone mineral content, especially the no-exercise/calcium group considering it had the smallest height gains, so the increase in bone mineral was likely due to retention of calcium in bone. The smallest percent change in bone mineral content was noted in the exercise/placebo group which may indicate that the exercise activated more remodeling units during the transient period, resulting in less net bone gain. However, there were no significant results indicating the transient effect of exercise on bone mineral. Bone mineral density decreased in all of the groups, mostly in the no-exercise/placebo group, which had the greatest height and total body area gains, thus resulting in a possible deficit in density because mineralization had not caught up with growth yet (Parfitt, 1994).

In subject set 2 (n=87) calcium supplementation had a positive effect at the trochanter and total intake was related positively to bone mineral changes at the femoral neck and lumbar spine supporting the transient effects of calcium. In subject set 4 (n=28) significant interactions were noted at the lumbar spine between 0-6 months, indicating positive effects of calcium for the exercise group but not for the no-exercise group. There was also a positive effect of calcium
Figure 5.3  Body Composition Percent Change 0-6 Months  
(subject set 4, n=28)
Figure 5.4 Change in Growth and Total Body Bone Mineral Variables 0-6 Months
(subject set 4, n=28)
supplementation for lumbar spine bone mineral density and total calcium intake was positively related to femoral neck and lumbar spine bone mineral density. Negative effects of exercise for total body and trochanter skeletal area (n=50) were also noted during this transient time. These results support the hypothesis of the transient period and the effects of intervention with calcium and exercise during this time. Blimkie et al. (1996) reported a trend for an increase in bone mineral density of the lumbar spine, and total body areal and volumetric (BMAD) densities in the first 13 weeks of a weight-training study in adolescent girls. That it was just a transient trend in the 26-week long study supports the remodeling transient hypothesis as well, although their results were not explained with the transient in mind. Although their results were indicative of the remodeling transient, they showed an increase in density at the lumbar spine due to exercise, (the program was intended to load the spine) their only intervention, whereas, the results reported here demonstrated an increase at this site due to calcium, and no significant effect due to exercise.

Although differences between the treatment groups were not significant the patterns of change depicted in figures 4.4-4.8 corresponded to the remodeling transient hypothesis. For example, the two exercise groups had the lowest percent increase in total body bone mineral content and the exercise-alone group had smaller percent increases in trochanter and lumbar spine densities. This pattern was also similar in subject set 3 (n=50). This finding supported increased remodeling due to the intervention of exercise. The group with only calcium supplementation had the greatest increases in total body bone mineral content which corresponds to the effect of calcium in reducing remodeling units during the transient period. Contradictory to anticipated patterns during the transient period was that the exercise and calcium-supplemented group showed the
greatest increases in lumbar spine bone mineral density and the exercise-only group had the smallest negative change in total body bone mineral density. The control group showed the greatest decreases in total body, femoral neck and trochanter bone density.

The results of the case studies also suggested the presence of the remodeling transient. In the first six months of intervention the case subject receiving calcium supplementation had greater percent changes for three of the bone mineral measures, total body, femoral neck and lumbar spine, than the exercise and exercise plus calcium subjects, again supporting that calcium decreases activation of remodeling units. The exercise-only subject had the smallest percent changes for all measures except total body bone mineral content, as compared to the exercise and calcium and calcium-only subject supporting that exercise increases activation of remodeling units. The percent changes observed in the exercise and calcium case subject fell, for the most part, in between the two other intervention cases indicating that calcium may have somewhat offset the increase in remodeling-unit activation due to the exercise. The evidence from this study supports the remodeling transient hypothesis, especially for calcium, and thus emphasizes the importance of accounting for it to evaluate true effects of some intervention on bone mineral. The transient has not been considered in any other published intervention study of adolescents, or even of adults, so future research in this area is essential to separate transient effects from the effects of intervention itself.

**Main Effects During the True Intervention Period of 6-18 months:**
If both exercise and calcium interventions are effective in increasing bone mineral changes beyond normal growth changes, then an increase in bone
mineral between 6-18 months, after the transient is accounted for, would be expected in the calcium and/or exercise treatment groups. Changes expected between 6-18 months were that the group with exercise and calcium intervention would show the greatest changes, followed by the exercise or calcium alone group, and the no intervention group would show the least positive changes in bone mineral. No significant differences were found, however, between the four different treatment groups, thus refuting the hypothesis. Figures 5.5 and 5.6 summarize the changes in body composition and total body bone mineral and area during the 6-18 month intervention period which helps explain the bone mineral change results. The exercise and calcium-supplemented group had the greatest increases in body weight and percent body fat. However, they also had the greatest gains in total body bone mineral content and density, once adjusted for weight change, indicating positive effects of the two interventions together, although not significantly greater. The exercise-only group had the smallest increases in total body bone mineral density possibly indicating that if calcium intake is not sufficient then the benefits of exercise are less.

Significant results which did appear during the true intervention period of 6-18 months included negative effects of exercise and calcium at the lumbar spine, and interaction in the femoral neck in subject set 4 (n=28) only. The negative effects of exercise and calcium, however, contradict the hypothesis stating that these factors would benefit bone mineral. Significance being found only in the set of subjects who were matched for maturation, indicated again the importance of controlling for this variable. When BMAD results were included there was also a significant interaction at the spine, indicating that calcium was beneficial.
Figure 5.5 Body Composition Percent Change 6-18 Months
(subject set 4, n=28)
Figure 5.6 Change in Growth and Total Body Bone Mineral Variables 6-18 Months
(subject set 4, n=28)
in the no-exercise group but not in the exercise group. These results suggest that the spine may be more sensitive to the remodeling effects of exercise, even if supplemented with calcium. The interaction effect at the femoral neck indicated that calcium was more beneficial to the exercise group than to the non-exercising group. The findings from this study indicate that the intervention of calcium supplementation and exercise were not successful in creating an osteogenic response, but there was a positive interaction between the two factors at the femoral neck indicating some effect and the need for further research to clarify it.

The patterns of change between 6-18 months in the subject groups (figures 4.4-4.8 and 5.5-5.6, means adjusted for change in body weight) give some insight into the possible direction of change influenced by the intervention, although there were not significant differences between the treatment groups. Total body bone mineral content increased in all groups. That part of this was due to growth is supported by the observed increases in height. The exercise and calcium-supplemented group had the greatest percent increases in bone mineral at all sites except lumbar spine. Total bone mineral density changes were all positive possibly indicating the direction of influence of the intervention, the end of the transient time, or mineralization was catching up to growth. The exercise-only group and calcium-only group actually had negative percent changes at the femoral neck and the smallest increases in total body bone mineral density and content and trochanter bone mineral content indicating that exercise, at a weight-bearing site, may only be beneficial with adequate calcium intake, and that calcium supplementation on its own, without the influence of exercise has no benefit to bone mineral. This suggestion is in agreement with other researchers (Anderson and Metz, 1992; Klesges et al., 1996; Specker et al., 1996). However,
the mean total calcium intakes for all groups were quite high already, above 800 mg/d, so the supplementation may have had no added benefit. This is in agreement with some researchers who have suggested that calcium supplementation may only be beneficial in those who had calcium deficient diets (Lee et al., 1994). Surprisingly the no-intervention group displayed the second greatest percent increases at all bone sites. This may have been because this group had a lower maturation level, therefore, greater bone mineral accretion rate initially.

In comparison to other exercise intervention studies in adolescents, the study by Blimkie et al. (1996) was only six months in duration so their results are only appropriately compared to the results of the remodeling period of this study. In comparison to intervention studies involving weight training in adults there was disagreement with Nelson et al. (1994) and Gleeson et al. (1990) who reported increases or maintenance in lumbar spine density in elderly women who weight trained for a year. Also in disagreement with this present study was the finding that in younger adults, aged 28-39 years, an 18-month training study similar in intensity to this study, with adequate calcium intake (>1000 mg/d), showed significant increases in lumbar spine bone mineral density as compared to the control group (Lohman et al., 1995). Snow-Harter et al. (1992), who investigated effects of resistance and endurance training in young women, also found significant increases in the lumbar spine, but not in proximal femur bone mineral density. Friedlander et al. (1995) found significant increases in femoral neck, trochanter, and lumbar spine bone mineral in young women who did a two-year program of aerobics and weight-training. In agreement with this present result, however, was Rockwell et al. (1990), who reported a decrease in lumbar spine density in a nine-month training study. These inconsistencies can
be explained by the fact that these studies are of different intervention duration, training intensities, different age groups and did not consider the remodeling transient. If the results between 0-18 months are considered, then exercise is considered as having had a positive effect on trochanter and total body bone mineral density which then agrees with the findings of Friedlander et al. (1995).

The fact that only one positive interaction and negative effects of exercise and calcium intervention were observed during the true intervention period of 6-18 months may indicate that the intervention was not successful in augmenting bone mineral. Other possible explanations for these results are that the study was not long enough (Kreipe, 1995), and that there was a drop in compliance over the last six months. As demonstrated by the strength tests, strength was only significantly greater in the exercise group than the non-exercise group between 0-6 mo. The final strength measures revealed no further increases in strength because of lower compliance but also possibly because subjects may not have progressively increased the amount of weight lifted, but continued training at a level to maintain their initial strength gains. The initial 6 months of training combined with the maintenance training could still have had a positive effect on bone, although not significant, since bone takes longer to adapt than muscle. Continued progressive training is necessary to indicate more clearly if weight-training could have a positive effect on bone. Skerry (1997) suggested that weight training may result in low strain rates, as opposed to the osteogenic high ones, and he also suggested that because of the diversity in loads from weight training it is difficult to provide clear conclusions as to the key factor of strain in providing the osteogenic response. As demonstrated by Kannus et al. (1995) and Haapasalo et al. (1994), exercise intervention during preadolescence may be more effective in increasing bone mineral than after puberty which is when this
intervention took place. There also could have been the possibility that other physical activity, which some subjects in the control and exercise groups participated in, confounded the results. Reviewing the physical activity records revealed that subjects ranged in activity level from quite sedentary, i.e., only walking, to active, i.e., involved in community recreational or school intramural sports. None of the girls were involved in serious competitive sports (this was an exclusion criterion) and the randomization of the subjects should have compensated for the range of physical activity. Since heredity is a major determinant of bone mineral, accounting for 46-62% of variance in bone density (Krall and Dawson-Hughes, 1993; McKay, 1995; Slemenda et al., 1991) it too could be confounding the results, but again the randomization of the subjects should compensate for this.

Calcium supplementation benefited the exercise group more so than the non-exercise group, in terms of increases in bone mineral, at some sites, suggesting a beneficial interaction between them. This interaction is in agreement with the ideas and data presented by Specker et al. (1996) which are discussed further in section 5.5. The fact that the exercise-only group often had the least, or one of the lowest percent changes, e.g., femoral neck, total body bone mineral content and density (n=50, n=28), and trochanter and spine (n=28), supported the idea that exercise is only beneficial to bone mineral if adequate calcium is available (Anderson and Metz, 1993; Klesges et al., 1996; Snow-Harter, 1994; Specker, 1996; Specker et al., 1996). However, the interactions where calcium was beneficial in the no-exercise group and not in the exercise group indicated an interaction between the two variables which was not expected. The effect, specifically at the lumbar spine, was actually negative when the two factors were
combined together. As mentioned above this may indicate that the spine is more sensitive to the effects of exercise.

The case studies also reflected patterns of change between 6-18 months that were consistent with the interaction hypothesis. Girls who were at least two years postmenarche at the start of the study were chosen to try to eliminate as much of the variation in rate of bone mineral accretion as possible. The weight-training and calcium-supplemented case had the highest gains in bone mineral at all sites, except lumbar spine, indicating the positive effects of calcium with exercise. The calcium-only case had the next largest gains in bone mineral at all sites, except total body, indicating the positive effects of calcium. The exercise-only case had the lowest changes in bone mineral at all sites possibly suggesting that the addition of exercise without adequate calcium may negatively affect bone mineral. This finding is also in agreement with other researchers who have indicated that exercise alone cannot offset the effects of inadequate calcium, that exercise is only beneficial to bone in an environment of adequate calcium, and that adequate calcium had a more positive effect on bone when combined with exercise (Anderson and Metz, 1993; Snow-Harter, 1994). These results, although only single examples, also support the hypothesis of an interaction between calcium and exercise on bone mineral changes.

The correlation analyses indicated significant association of exercise compliance with bone mineral change for total body, femoral neck, and lumbar spine densities (0-6 and/or 0-18 months), which argues against the remodeling transient effects of exercise, but is consistent with the research studies reporting significant predictors of bone mineral from recall studies (Fehily et al., 1992; Teegarden et al., 1996; Valimaki et al., 1994). There was no significant

234
correlation observed between exercise compliance and bone mineral changes during the true intervention period of 6-18 months though. This may be because compliance tended to decrease over the last six months thus possibly affecting strength measures and further increases in bone mineral, as explained above.

Strength gains were significant in the lower body, but not upper body for all subject sets and this may also be explained by the drop in compliance over the last few months and failure to continue with progressive training resulting in a detraining effect on muscle. Most studies investigating the relationship between muscular strength and bone mineral density have reported significant associations (Eickhoff et al., 1993; Nordstrom et al., 1997 and 1996; Tsuji et al., 1995), but this was not the case in this present study. Weight-training intervention studies have reported significant increases in strength with concurrent increases in bone mineral (Friedlander et al., 1995; Snow-Harter et al., 1992) or without increases in bone mineral (Gleeson et al., 1990; Lohman et al., 1995; Peterson et al., 1990; Pruitt et al., 1995). In this present study only upper body strength was significantly correlated to total body bone mineral density change between 0-6 months and it was a negative correlation. This may be indirectly indicative of the effects of weight-training during the remodeling transient period. There were no significant correlations between exercise compliance, lean body mass changes and strength changes which is suggestive that the exercise intervention may not have been intense enough.

Lean body mass change was associated with bone mineral change for total body bone mineral content, femoral neck, trochanter and lumbar spine during different periods of the study. This result is consistent with studies which investigated the association between body weight and composition with
adolescent bone mineral measures (Manzoni et al., 1996; Rico et al., 1994). However, change in lean body mass was not associated with exercise compliance or strength gains. Again, this may be because of low compliance or failure to progressively train. Also, as stated by many researchers (Boot et al., 1997; Glastre et al., 1990; Morris et al., 1997; Reid et al., 1992; Rubin et al., 1993; Wardlaw, 1996) these present results found body weight change and maturation to be the two factors accounting for the most variance in bone mineral content change (56%) between 6-18 months. The relationships between weight change and bone mineral changes were generally higher than those between lean body mass and bone mineral changes. At least one of these factors, weight change or maturation, was a significant contributor to variance in bone mineral change for all bone mineral measures, except the trochanter, throughout all or part of the study duration. The strong associations observed here between body weight change, maturation and changes in bone mineral indicate that, despite lifestyle intervention such as exercise, these factors have the greatest influence on bone mineral changes during this rapid growth phase of adolescence. However, many of these subjects were in the late stage of adolescence, when growth is decelerating, by the end of the study.

There have been no published weight-training and calcium-supplementation intervention studies completed on adolescents, of long enough duration to observe effects beyond the transient, which makes it difficult to compare these results. These results are not in agreement with the numerous studies and review articles on the benefits of exercise for bone mineral (Bailey et al., 1990; Bailey and Martin, 1994; Chillibeck, 1995; Forwood and Burr, 1993; Geusens and Dequeker, 1991; Martin and Brown, 1989; Snow-Harter and Marcus, 1991) or with the few recent exercise studies on preadolescents (Dyson et al., 1997;
The fact that the control group had greater gains than some of the intervention groups possibly indicates that the adolescent girls in this study were active enough and ingesting adequate calcium to support bone mineral gains.

5.4 Total Calcium Intake and Bone Mineral Changes:

Of the 87 girls who completed the study only 37% met the Canadian RNI for 13-15 year olds of 1000 mg/d of calcium through their average dietary intake, however, the mean intake was only slightly under at 894 mg/d. This percentage was very similar to the 35% of adolescents in the Vancouver area who met the RNI in the study by Barr (1994), and Whiting et al. (1995) who also found that more than 25% of girls in Saskatoon were below the RNI. After supplementation 76% of the girls in this study met the RNI. Despite careful and standardized direction, and relatively high validity of three-day food records and food frequency questionnaires there is still the possibility of under or over reporting intakes (Livingstone et al., 1997; Schoeller, 1990).

There were very few main effects of supplemented calcium on changes in bone mineral found in subjects sets 3 and 4 in this study and 2/3 of the significant effects were at the lumbar spine site (positive effect 0-6 months, negative effect 6-18 months) and 1/3 was at the trochanter (positive effect 0-18 months). Calcium's positive effect between 0-6 months, also demonstrated in subject set 2 (n=87) at this site, supports the remodeling hypothesis. The negative effect between 6-18 months, however, refutes the hypothesis of the benefits of calcium supplementation on bone mineral. Significant positive correlations of total calcium intake with femoral neck and lumbar spine bone mineral changes from 0-6 months were also found, again supporting the remodeling transient
hypothesis. The site-specificity agrees with associations reported by Ruiz et al. (1995) but only partly with Valimaki et al. (1994) who concluded that the femoral neck was more sensitive to calcium than the spine. Previous literature as well as this study show no consistent effects of calcium on any bone site. From the results obtained in this research it appears that calcium supplementation has no positive effect on bone mineral changes during the intervention period.

The three calcium-supplementation studies completed in adolescents and preadolescents all showed significant increases in bone mineral in the supplemented group over the unsupplemented group (Chan, 1995; Johnston et al., 1992; Lloyd et al., 1993). The control groups in these studies ranged in intake between approximately 700-1000 mg/d and the supplemented group received at least 40% more. The reason we may have not found as many significant effects of calcium supplementation is because the remodeling transient was considered. If the 0-18 month results are considered then a positive effect of calcium for trochanter and femoral neck bone mineral density would be concluded. Another reason why supplementation had no effect during the intervention period could have been because our subjects were a bit older and more mature than in the above mentioned research studies, therefore, calcium requirements would be decreasing. Another possible explanation for the no-effect result of supplementation is that other dietary aspects and their impact on calcium absorption were not considered. For example, fibre, phytate, sodium, food source of calcium, calcium to protein ratio, can all affect the absorption of calcium and thus the amount being retained in the bones (Heaney, 1993; Matkovic et al., 1995; Prince, 1993; Toss, 1992; Weaver and Heaney, 1991; Weaver and Plawecki, 1994). Also, the mean intakes for the unsupplemented groups were all above 800 mg/d and negative effects on bone mineral were not
observed in our subjects unless intake was less than 600 mg/d, which is similar to the result found by Ruiz et al. (1995), in a group of slightly younger subjects (7-15 years), where bone mineral density was not negatively affected unless intakes were under 1000 mg/d. The study reported here is in partial agreement with Johnston et al. (1992) who found no effect of supplementation in the postpubertal twins and concluded calcium supplementation may have more of an effect in prepubertal children.

In comparing bone mineral densities of individuals with high and with low calcium intake there was a significant difference during the bone remodeling transient time for total body and lumbar spine with higher values observed in the high intake subjects. This indicated that the effect of calcium in decreasing the remodeling space may prevent some of the bone mineral decrease due to the introduction of exercise during this transient time. The positive association of calcium intake with lumbar spine bone mineral density (0-6 and 0-18 months) is in agreement with Ruiz et al. (1995). The high calcium-intake group indicated a trend for greater femoral neck bone mineral density increases over the duration of the study which agrees with the positive relationship between calcium intake and femoral neck density reported by Valimaki et al. (1994). The high versus low calcium-intake comparison showed some evidence that intakes less than 600 mg/d negatively affected bone density agreeing closely with Ruiz et al. (1995) and Chan (1991).

Calcium has been described as a threshold nutrient where above a certain intake there are no calcium balance gains and thus no further gains in bone mineral (Matkovic and Heaney, 1992). Balance threshold was reported as 1480 mg/d by Matkovic and Heaney (1992) as well as Andon et al. (1994). In this study
calcium intake was plotted against changes in total body bone mineral over the 18-month period indicating a calcium threshold effect in agreement with the above mentioned studies, with the curve leveling off at about 1300-1400 mg (figure 4.12).

Retention efficiency was significantly correlated with maturation \( (r=-0.53) \) which is in agreement with research indicating that retention efficiency is lower the higher the maturity status (Abrams and Stuff, 1994). Retention appears to be higher when demands for calcium are increased such as during the rapid growth phase of adolescence (Matkovic, 1991; Abrams and Stuff, 1994). The case studies of calcium retention in this study agreed with this in that retention efficiency was generally higher for the girls who were fewer months past menarche (mean retention efficiency was 9.5% vs. 6% for girls 2.5-3.5 years postmenarche). In the low-maturational status case studies, the case with the highest intake of calcium of 2151 mg/d also had the highest gain in bone mineral of 150 g over the year and the lowest retention efficiency of 6%. This is in agreement with Matkovic et al. (1990) who stated that adolescent girls ingesting higher quantities of calcium and subsequent lower absorption rates may still be retaining more calcium overall. In this study, however, a significant positive correlation of \( r=0.27 \) between calcium retention efficiency and total calcium intake indicated that retention efficiency increased with increasing calcium intake. This disagrees with Matkovic et al.'s (1990) study, but may suggest a mechanism whereby the adolescent body increases retention efficiency to compensate for the increased calcium need during this rapid growth phase (Matkovic, 1991).

The retention efficiency percentages found in our case studies, based on their change in bone mineral content between 6-18 months and total calcium intake,
were much lower than those reported by Martin et al. (1997) whose values ranged from 37% in the low calcium intake case to 19% in the high calcium intake case. In the results of this study reported here, retention efficiency ranged from 3% -7% in the low intake cases, to 9-13% in the medium intake case, to 6% for the high calcium intake case. Retention efficiency values were also lower than the average of 20.3% reported by Weaver et al. (1995) and much lower than the 30% reported from the adolescent calcium balance studies completed by Matkovic et al. (1992). Reasons for the differences may be that our subjects were older, more mature and did not gain nearly as much bone mineral (20-150 g vs. 244-338 g) than the 11-year old cases used by Martin et al. (1997). Calcium retention efficiency will drop from 20.3% (Weaver et al., 1995) to zero from early adolescence to early adulthood at which point there is calcium balance and no net gain so retention efficiency would be zero. The girls in this study were getting closer to early adulthood than those in Martin et al.'s (1997) study, therefore, explaining the lower retention efficiency. Also, those who gained little bone mineral could have been late maturers, or had no height gain. Another explanation is the large standard deviation in bone mineral gained indicating that the data were not normally distributed about the mean suggesting some might have had very large gains. Bailey et al. (1997) knew peak bone mineral accrual corresponded to menarche in their subjects. In the study reported here, this situation is only assumed and if peak bone mineral accrual and menarche did not correspond then retention efficiency could be affected. This provides another possible reason for the different retention efficiencies observed between the studies.
5.5 Interaction Between Physical Activity and Calcium

Through the review of literature it became evident that many factors, both genetic and lifestyle related, affect bone mineral accretion. The effects of these factors do not necessarily stand alone and, therefore, should be explained for the effects of their possible interaction. An interaction effect means that the relationship between an independent variable (e.g., calcium) and the dependent variable (e.g., bone mineral) is altered by the presence of different levels of another independent variable (e.g., exercise). The results of this study indicated that there were interactions between exercise and calcium effecting changes in bone mineral at various sites at certain times throughout the study. These significant interactions occurred for total body bone mineral content (6-18 months, \( n=87 \)), and for femoral neck bone mineral density (0-6 months, \( n=28 \) and 50, and 6-18 months, \( n=28 \)). Interactions were also noted for lumbar spine bone mineral density (0-18 months, \( n=50 \)), total body skeletal area (0-6 and 0-18 months, \( n=28 \)) and bicristal bone breadth (0-18 months, \( n=28 \)).

The effects of these interactions were different for the different time periods of the study, for example, between 0-6 months the interaction effect was that calcium was beneficial in the no-exercise group but not in the exercise group, whereas between 6-18 months the effect was opposite in that calcium was beneficial in the exercise group and not in the no-exercise group. This later effect suggests that calcium is more effective with exercise, after the remodeling transient, since the percent gains in the group with both factors were greater than the no-exercise calcium group. The interactions between 0-18 months for bone breadth and skeletal area also had this positive interaction effect of calcium with exercise.

This agrees with our hypothesis and the suggestions from the study by Specker et al. (1996). The effect of the interaction between 0-6 months is different than expected, i.e., the factors act differently together than they did on their own and...
had a negative effect. The effect of the interaction at the lumbar spine between 0-18 months was also negative so calcium supplementation in the exercise group resulted in smaller increases than either the exercise or calcium groups alone. This may suggest presence of the remodeling transient considering the time frame of this interaction.

The pattern of change in the case studies, as well as in the figures 4.4 - 4.8, which reflect the means across time for the four treatment groups in subject set 4 (n=28), also suggested a positive effect on bone mineral of calcium in the exercise group. For example, the exercise and calcium-supplemented group tended to have the greatest changes and the exercise-only group tended to have the least changes in bone mineral (6-18 months). Although the case studies and patterns of change are just examples and not supported by statistical analysis, they are in agreement with the review by Specker (1996) who concluded that an interaction of calcium and exercise existed which indicated that exercise only had an effect if calcium was adequate (>1000 mg/d) and that there was no effect of calcium in increasing bone mineral without exercise. The results of a study by Specker et al. (1996) investigating interaction of exercise and calcium in infants mimicked this pattern, however, it is difficult to compare results of adolescents and infants.

5.6 Skeletal Area, Bone Size and Bone Mineral Apparent Density (BMAD) Changes

Total body skeletal area and trochanter area increased with time in our subjects mostly indicating growth, since there were no significant differences between the treatment groups. There was a negative effect of exercise for total body and trochanter skeletal area in the n=50 group and trends for main effects of exercise for spine (negative), femoral neck (positive) and trochanter area (negative) in
subject set 4, n=28 between 0-6 months. The negative effects support the bone remodeling transient hypothesis. The only increase observed in a bone breadth measure, the bicristal breadth measured by anthropometry, corresponded with the increase in femoral neck area. The bicristal breadth of the hip showed significant increases due to exercise (0-6 months) and an interaction effect (0-18 months), indicating that the calcium was beneficial in the exercise group. Calcium supplementation only had a significant negative effect for lumbar spine area between 6-18 months, which contradicts the hypothesis of the anticipated effects of calcium supplementation. These results are in disagreement with the one other study published so far that has reported changes in skeletal area of adolescents (Lloyd et al., 1996). Lloyd et al. (1996) intervened only with calcium, and not exercise, and found a significant effect of calcium in increasing whole body, pelvis and lumbar spine skeletal area. The results of this study showed a negative effect of calcium for lumbar spine area, if looking at the mean change of the two calcium-supplemented groups. The calcium-only group, however, had greater increases in skeletal area than the exercise only or both interventions together. The no-exercise/placebo group, though, had the greatest changes in skeletal area for most cites except femoral neck, again refuting the hypothesis. Morris et al. (1997) also reported an increase in femoral neck area after a year of regular impact exercise, but the subjects were preadolescents. These results do not support the hypothesis of increased bone size and skeletal area due to exercise and calcium intervention, since most changes were negative and occurred during the transient time.

These results did indicate change in bone size and area, though, regardless of the timing of change, which reinforces the greater chance of error and misinterpretation of areal bone density results and the importance of accounting
for this size artifact through techniques such as BMAD. BMAD was used in this study to observe density changes in the femoral neck and lumbar spine as these sites are the most valid and were reported in the other studies correcting for bone size. Analyses of BMAD changes resulted in four significant results for interactions and one trend for a positive effect of calcium. Three of these results were for the same sites and time frames as the areal bone density significant results of which there were seven. BMAD resulted in interactions for lumbar spine between 0-6 and 6-18 months which areal density did not show. However, BMAD tended to have higher P values, whether significance was reached or not, than did areal bone density results indicating that areal density measures may show significant changes more often. The reason for this may be because of the confounder of bone size changes or differences. This is in agreement with Bhudhikanok et al. (1996) and Katzman et al. (1991) who stated that bone size changes can account for most differences observed in areal density measures. These results indicated that correction of bone size should be considered to determine true intervention effects on bone mineral change.
Chapter 6. Summary and Conclusions

6.1 Summary

Osteoporosis is a progressive disease affecting more and more elderly persons, especially women, resulting in pain, disability and decreased quality of life. Previous research has linked many lifestyle related factors affecting the attainment, maintenance and loss of bone mineral. Manipulation of these lifestyle factors could positively affect bone mineral accrual during the growth phase of adolescence and possibly provide the strongest preventive factor for osteoporosis. Implementing a weight-training and calcium-supplementation program and studying the effects of these factors on bone mineral was the purpose of this study with the intent of providing a protective factor for osteoporosis. Implementing health programs in the school setting is ideal since it addresses the majority of adolescents during a time when lifestyle habits are being developed through the influence of significant others. With exercise participation rates decreasing during adolescence, especially in females, it seems like an appropriate time to introduce such a health promotion program not only for bone health benefits, but for other health and fitness benefits as well.

This is the first study to examine the bone remodeling transient and the interaction of exercise and calcium, as well as their separate effects, on bone mineral and bone size changes in a long-term intervention study of adolescent girls. Four North Vancouver schools agreed to support the 18-month weight-training and calcium-supplementation study with 108 healthy, normally active female students volunteering to participate. The study was not a true randomized study as participation in the exercise aspect of the study was based on the school the subjects attended. Calcium supplementation or placebo was randomized. Screening and controlling for other factors known to affect bone
mineral, as well as subject matching were completed to decrease variance and confounding variables as much as possible. Confounding effects of growth and maturation were expected and controlled for through the matching of subjects (on maturation, body weight and height), and analysis techniques such as BMAD, ANCOVA and percent change. Challenges with subject compliance, due to other school commitments and lifestyle changes, for example, were also expected. Careful planning, therefore, through use of the PRECEDE PROCEED model of health promotion planning and evaluation, of the intervention program as well as incentives were incorporated to enhance compliance. The number of drop-out subjects and low compliance in some subjects does limit the analysis because of decreasing subject group size. These limitations must be considered in the application of results.

Weight training was completed three times per week in the school weight room and calcium supplementation was provided daily through two tablets of 500 mg each. Compliance, menstrual, physical activity records were kept throughout the study and dietary analysis, anthropometric and bone mineral measurements were taken three times during the study: at baseline, six months into the program and at the end of the 18 months. Analyses included investigating changes between 0-6 months to test for indication of a bone remodeling transient and between 6-18 months, the true intervention period, to test for interaction of calcium and exercise, main effects of calcium or exercise, and differences between treatment groups. Correlation analyses, case studies, investigation of total calcium effects and calcium retention, skeletal area, as well as BMAD, to account for differences or changes in size of bone, were completed to help explain and determine the effects of the intervention.
Based on the study design, limitations, and results a number of conclusions have been made which have implications and practical applications for bone mineral accrual during adolescence.

6.2 Conclusions

1. There was no benefit of one year of calcium supplementation on bone mineral content, density, bone size or skeletal area in healthy adolescent girls, who were ingesting close to the Canadian RNI of calcium, after accounting for the bone remodeling transient.

2. There was no benefit of one year of a progressive weight-training program, designed to facilitate strength gains, on bone mineral content, density, bone size or skeletal area in healthy adolescent girls, after accounting for the bone remodeling transient.

3. There was a positive interaction between calcium supplementation and weight training on femoral neck bone mineral density, bicristal bone breadth and total body skeletal area in adolescent girls indicating that calcium supplementation was beneficial to the weight-training group.

4. There was a negative interaction between calcium supplementation and weight training on femoral neck bone mineral density during the bone remodeling transient period in adolescent girls indicating that calcium was beneficial to the non-exercising groups, i.e., calcium had a negative effect in the exercise group.
5. There was evidence of a bone remodeling transient during the first six months of the weight-training and calcium-supplementation intervention in adolescent girls indicated by: the positive effect of calcium on lumbar spine bone mineral density, the negative interaction on femoral neck bone mineral density, the negative effects of exercise for total body and trochanter skeletal area, and the positive correlations of total calcium intake with femoral neck and lumbar spine bone mineral density.

6. Factors relating to time commitment, social aspects and enjoyment, aesthetics, increased knowledge and awareness of osteoporosis, health and nutrition, had the greatest impact on compliance with the school-based weight-training and calcium-supplementation program in middle to upper-class adolescent girls.

7. 18 months of a school-based progressive weight-training program, designed to increase strength, increased lower body strength in adolescent girls.

8. High calcium intake (>1200 mg/d), as opposed to low calcium intake, (<600 mg/d) positively affected total body bone mineral density in adolescent girls.

9. Calcium retention efficiency decreased as maturational status increased in adolescent girls.

10. Maturation and/or body weight change accounted for most of the variance in bone mineral change of adolescent girls participating in the 18-month calcium-supplementation and weight-training intervention program.
11. Calculation of bone mineral apparent density for the femoral neck and lumbar spine sites allowed for consideration of changes in bone size in the adolescent girls throughout the duration of the intervention. Fewer significant results and higher P values for BMAD for the same change comparisons, indicated that areal density overestimated some bone mineral changes and, therefore, should be considered when determining changes in bone mineral during growth or during an intervention.

6.3 Implications

Based on the results and conclusions of this study weight-training and calcium supplementation do not benefit bone mineral in postmenarcheal adolescent girls. The low to moderate daily activity and ingestion of an amount of calcium close to the Canadian RNI may be enough to facilitate bone mineral gains in postmenarcheal girls. However, the interactions noted between exercise and calcium at the weight-bearing femoral neck site should be considered in the recommendations to adolescents for healthy lifestyle practices as well as in future research.

Through careful planning the intervention program was successful in that the participants enjoyed themselves, learned new skills, increased bone mineral and strength in some areas, and learned about osteoporosis, health, activity and nutrition. A curriculum package could be developed for health and physical education teachers including a theoretical component to learn about the factors affecting bone mass, and also including an active component to load the bones on a regular basis. Inclusion of a variety of exercises, not only weight training, should be considered to possibly enhance compliance with an exercise program.
The planning for a school setting is already done, using the PRECEDE PROCEED model. The impact that such a program could have on decreasing incidence of osteoporosis by increasing knowledge, possibly increasing bone mass, and by adoption of healthy lifestyle practices in adolescents could be great.

The results of this study also provide information about normative values for bone mineral in adolescents which could have numerous clinical applications. Plus they contribute to the body of knowledge in this area, which at this point is limited due to the very few longitudinal intervention studies investigating the impact of calcium and exercise on adolescent bone. The results also provide information regarding the effects of, and interaction between, weight training and calcium supplementation, after accounting for the bone remodeling transient, which has not been done previously. The results provide information on size and area changes, variables which may prove to be important factors in adolescent bone changes and osteoporosis prevention as more research is completed in this area. The importance for controlling for maturation, body weight change and bone size when comparing bone mineral changes was also made evident. The results and conclusions should be used as the basis of future research in this area.

6.4 Future Research
After considering the positive aspects and the limitations of this study, in terms of study design, future research needs to control for, through matching, the differences in rates of bone mineral accretion in adolescent subjects. This way any changes seen in bone mineral could be attributed to the intervention of the exercise and/or calcium-supplementation program. The large variation in rates
of bone mineral accrual, even for subjects matched on maturational status, could have overshadowed most effects of the intervention program in this study. If subjects were followed for two years around the time of menarche, close to peak bone mineral accrual, growth velocity curves could be plotted and subjects matched on this aspect. Then the intervention program could be started, again to test for main effects and interaction of exercise and calcium, after considering the bone remodeling transient period. Along with this, and based on the results of this study, factors affecting program compliance in adolescents should be further investigated. Control over training procedures to ensure training effectiveness should be included in the research design. Considering that calcium supplementation and exercise did not have an effect on these adolescent girls, a similar study undertaken in premenarcheal girls may result in the original anticipated effects.

Another valuable contribution to the understanding of the effects of this type of intervention during adolescence would be to follow-up with these subjects into adulthood to observe changes and the persistence of any of the effects shown in this study, as well as to see if the long-term goal of osteoporosis prevention is met.
References


256


261


Tonkin. B. C. Adolescent Health Survey. (1994).


exposure is very low (about 1/10th of a normal x-ray) so is acceptable for repeated measures on children and adolescents. The bone densitometer is able to take a picture of bone tissue, display it on a computer which then determines its density. The more dense bone tissue is the stronger and more resistant it is to stress and osteoporotic fractures. The actual measurement requires the subject to just lie on their back while the scan moves over the length of their body. The measure involves absolutely no discomfort and takes about 20 minutes.

Subjects will be either in a control group or experimental group as determined by the school they attend. Schools have been selected as an experimental or control school, therefore, by consenting to participate you must be willing to be in either group. You will not know which group you will be in until the study begins. The experimental group will be involved in a progressive weight-training program and receive a daily calcium supplementation for the year. Three sessions of about 40 minutes each will be required to complete the exercises and will be scheduled into part of your regular school day. The sessions will be done in your school weight room under the supervision of your physical education instructor, the investigator or another qualified individual. Subjects will be taught by the investigator how to use the weights properly and how to do the exercises safely. Exercises for each of the major muscle groups will be included. The control group will be randomized into two groups. One will receive a daily calcium supplementation and the other will not. The control group will not participate in the weight-training program but will continue their current lifestyle for the year. The daily calcium supplement of 500 mg is to ensure subjects are within the daily recommended nutrient intake range.

Subjects will be required to fill out exercise log books if they are in the experimental group and all subjects will need to fill out the daily supplementation checklist. Every 3 months all subjects will complete the lifestyle questionnaire and 3-day dietary analysis. These questionnaires will only take about 30 min. to complete.

The only possible risk of participating in this study is slightly sore or tired muscles from the weight-training program and strength testing. The benefits of participating in the study include possible nutritional benefits from the calcium supplementation, learning about bone density, gaining information from the results of the study concerning bone health which have implications for prevention of osteoporosis and for quality of life (meaning that which makes life enjoyable, satisfying and rewarding). The experimental group will also experience the added benefits of regular exercise which may result in increased muscular strength, endurance and therefore, an increased overall level of fitness, increased knowledge of healthy lifestyle, possibly increased bone density and bone size resulting in a lower risk for developing osteoporosis. The
The experimental group may also enjoy the social benefits of exercising with a group. The control group will have the opportunity to participate in the training program after the year study.

There will be no monetary reward for participating in the study but added incentives will be included in the program to increase enjoyment of participation.

Please be aware that you are free to decline to enter the study as well as to withdraw from this study at any time throughout its course without jeopardizing school marks or class standing. Please notify the investigator immediately if you wish to withdraw at anytime during the study.

If any questions or concerns arise at any point during the study you may contact the investigator or faculty supervisor.

By signing below, I, ____________________________ consent ______/do not consent ______ to participate in the study under the above mentioned conditions and only if my parent/legal guardian also gives permission for my participation. I also understand that I may withdraw from the study at anytime and will be given a copy of this document and any other attachments for my own records.

__________________________________________  ____________________________
name of student (please print clearly)  date

__________________________________________  ____________________________
signature of student  date

I, ____________________________ who is a parent/legal guardian of ____________________________ whose signature appears above, give permission for his/her participation in the above mentioned study under the stated conditions. I also understand that I may withdraw my child from the study at any time and will receive copies of this and other attachments for my records.

__________________________________________
name of parent or guardian (please print clearly)

__________________________________________  ____________________________
signature of parent or guardian  date
Figure 2. Breast Development
If you checked physical activity in question 1 above please indicate:

- type of activity
- recreational or competitive
- if competitive, at what level?
- how many hours per week?
- do you belong to a specific club or group? Yes or No
- if yes please indicate
- how many times do you meet per week?
- how many years have you been participating?

B. Eating Habits

1. Do you eat either cheese, yogurt, milk, broccoli, or spinach daily? Yes or No
   If no, how often do you eat them? 

2. Do you drink coffee? Yes or No 
   Do you drink tea? Yes or No 
   Do you drink colas? Yes or No 

3. Do you drink alcohol regularly? Yes or No 
   If yes, how many glasses per week? 
   What type? 

4. Do you follow any specific diet or eating plan? Yes or No 
   If yes, please explain briefly the foods, quantities, eating patterns and the name of the program if applicable.
5. Do you eat regular meals throughout the day? eg. 3-5 meals scattered in the day. Yes or No.
If no, please explain your meal patterns.

6. Have you ever been on a calorie restricted diet? Yes or No.
If yes, when and for how long?

7. Do you have anorexia nervosa or bulimia or any symptoms of these conditions? Yes or No or don't know.
If yes, please explain.
If yes, are you getting medical treatment? Yes or No.

8. Do you take any vitamin supplements? Yes or No.
If yes, what and how often?

C. General Health

1. Are you taking any medication? Yes or No.
If yes, what? For how long? For what reason?

2. Has your doctor ever diagnosed you with any illness/injury of any sort that may affect your participation in this study or in physical activity? Yes or No.
If yes, please indicate what and any treatment you are involved in.

4. When was the date of your last physical exam?

5. Has anyone in your family been diagnosed with osteoporosis? Yes or No.
If yes, who?

6. Are you taking oral contraceptives? Yes or No.

7. Do you smoke? Y or N.
If yes, how many/day? How long have you smoked for?
Does anyone in your home smoke? Yes or No.
If yes, who and how much?

Thank you for completing this questionnaire.
Appendix E.
Subject Matching Procedure

The purpose of matching each control subject with an experimental subject was to eliminate as many confounding variables as possible, especially that of growth, in order to determine a real change in bone density and size due to the weight-training and/or calcium supplementation. A computer matching program was written specifically for this purpose.

The subjects were matched according to body weight, height, and maturational status (number of months past menarche). The program read in the three characteristics from one set of individuals (the experimental group) then the same characteristics for the second set of individuals (the control group). The individuals from the one set were matched with the individuals from the other so that the numerical difference between them was minimized.

The total difference between each pair equaled the sum of the squares of the difference between the control and experimental individuals for each of the 3 characteristics. The program repeated the total difference calculation 2916 times (54 x 54); the number of subjects in each of the control and experimental groups. For example the first control person was compared to every experimental person and the difference calculated for the three characteristics. The procedure was then repeated for the next control person and so on. The difference matrix with all 2916 calculated differences then sorted form lowest to highest total difference. The first 54 pairs, for which no repetition of an individual occurred, were selected as the matched pairs with the least total difference.

Weighting of the three characteristics:

The three characteristics of weight, height and maturational age contribute differently to bone density. Weight is the most influential of the three and therefore, it was assigned a greater weighting than the other 2 characteristics when determining total difference. Maturation was given the next highest weighting factor and height was of least importance to the matching procedure. When total difference was calculated weight was the highest priority to match the closest. The weighting factors were 4, 2, 1 respectively.

The three characteristics had a different range of magnitude which could have introduced a bias in the matching process in favor of the larger quantities. To eliminate this bias and to ensure all 3 characteristics were treated equally (before weighting factors assigned) each value in the data set for each characteristic was divided by the maximum value recorded for the characteristic. Therefore, the range of values for each characteristic was between zero and one.
Appendix F.
Description of Measurement Procedures

Subjects were wearing shorts and a T-shirt for all measurements. All measurements, except for the strength tests, were taken at the hospital.

Bone Densitometry Measurements:

These measurements were taken at St. Paul's Nuclear Medicine Department using a Norland XR26 DPX dual-energy x-ray absorptiometry machine and followed procedures as outlined in the XR Series Operators Guide (Norland, 1992). Subjects basically lay on a table type platform on their back in an outstretched relaxed position for the duration of the test. A scan moves over the appropriate part of the body like an x-ray procedure. The scan was projected onto a computer screen for analysis and a printout (see Appendix H). All scans were taken by the same two Nuclear Medicine technicians with the standardized procedures communicated between them. Subjects wore no metal, jewelry or hard plastic.

1. Whole-body scan was taken with subjects lying on their back with arms by sides moved laterally so hands were just inside the scan area (marked with tape on the bed). Arms were given a slight pull to ensure shoulders were down and palms were face down with fingers together. The head was straight and chin up so mandible was no over the clavicle. A gentle pull was given to the legs simultaneously to ensure the body was straight. Feet were placed with heels apart and big toes inverted and taped in place 1" apart. The scan moved at the high precision speed of 90 mm/s and took close to 26 minutes to complete.

2. Lumbar spine scan was taken with subjects lying on their back and a standard box placed under their legs so their hips and knees were bent at 90 degrees and their back was flat on the bed. The markers of the bottom of the sternum and just below the iliac crest were used to indicate the length of the scan. The scan moved at the standard speed of 60 mm/s and took about 7 minutes.

3. Hip scan measurement required subjects to lay on their back as for the whole body scan. Feet were spread apart with a standard block of 43.5 cm. A brace was placed under their thighs and velcro straps were placed around the thighs and secured to the brace. Each of the right and left leg straps were tightened to the same scale to cause inward rotation of the leg. The markers used for the length of the scan were the greater trochanteric tuberosity and the mid femur. The scan moved at the standard speed of 45 mm/s and took about 7 minutes to complete.
Body Composition Measurements:

Procedures for the following anthropometric measurements are detailed in numerous other publications (Docherty, 1995; Fitness and Amateur Sport, 1986; Malina and Bouchard, 1991; Willis, 1989; Yuhasz, 1987). The same measurement instruments were used on every subject during all three measurement sessions and each subject was measured by the same investigator on all three occasions.

1. Height was measured with subjects standing barefoot against a wall scale in the Frankfort horizontal plane to the nearest tenth of a centimeter.

2. Weight was measured on a balance beam scale measured to the nearest tenth of a kilogram.

3. Circumferences were measured using an anthropometric locking tape, with subjects standing relaxed in anatomical position, to the nearest tenth of a centimeter. The sites measured were:

   waist       hips
   calf        mid thigh
   forearm     upper arm

4. All skinfold sites measured were standard sites. All measurements were landmarked and taken directly on the skin on the right side of the body using Harpenden calipers and subjects standing relaxed in appropriate positions. Skinfolds were measured to the nearest tenth of a millimeter. The sites measured were:

   biceps       triceps
   subscapular  abdominal
   suprailiac   front thigh
   medical calf

Bone Size (Breadth) Measurements:

1. All measurements were taken at standard sites on the right side of the body with modified Vernier calipers. For each bone breadth the calipers were placed over the bony processes and squeezed firmly to eliminate soft tissue over the processes and the scale was read on the calipers to the nearest hundredth of a centimeter. The breadths measured were:
Strength Measurements:

1. One repetition maximum (1RM) tests were completed using multi-station weight apparatus. Subjects completed a warm up and were instructed on how to execute each test exercise. For each test subjects did one repetition at a predicted challenging weight. One plate was added for each repetition until the subject was not able to execute the lift. The maximum lift was achieved within three repetitions so the scores were not compromised by fatigue. The last weight successfully lifted was recorded. The exercise tests included were:

   - bench press
   - hamstring curl
   - biceps curl
   - seated row
   - shoulder press
   - quadriceps extension
   - triceps extension

Questionnaires

1. A food-frequency questionnaire was orally presented to each subject individually in private. The questions were asked by the author each time for every subject in the same manner.

2. Three-day dietary records were explained to each subject thoroughly as well as written directions were included.

3. The lifestyle, self-rated maturational and program questionnaire (last test session only) were completed at the testing sessions, mailed or given to subjects to complete on their own and hand or mail back to the investigator. The same directions were given for each subject. The self-rated maturational questionnaire was chosen because it was highly recommended for its simplicity, practicality, reproducibility and privacy (Matsudo and Matsudo, 1993). Indices of validity for self-rated Tanner staging ranged from 56.7% - 67.6% for girls aged 11-18 years but when one stage variation was assumed variation ranged from 94.8% - 96% (Matsudo and Matsudo, 1993).
Appendix G.

St. Paul's Hospital Nuclear Medicine Waiver
The DEXA test which you will be having today involves a low level radiation exposure. While this exposure is extremely low and there are no known side effects, the test will not be performed if there is a pregnancy.

By signing this consent form you are stating that, to the best of your knowledge, you are not pregnant at this time. If you have any doubts about this please do not sign the form until you have discussed the possibility of pregnancy with the technologist.

Student Name (please print) ________________________________

_________________________  ______________________  ____________
Student Signature                        Date                        Witness
Appendix H.

DEXA Printout
ST. PAUL'S HOSPITAL NUCLEAR MEDICINE DEPARTMENT
1081 Burrard St. Vancouver, B.C. V6Z 1Y6 Ph. 631-5008

Name
ID J6737
Age 18
Sex Female

Ethnic CAUCASIAN
Height 167.4
Weight 58.4

L H Body 06/02/96 Sequence 3

Bone image not for diagnosis

Total BMD (g/cm ) : 0.942
Total BMC (g) : 2424
Total Lean Mass(g) : 40390
Total Fat Mass (g) : 14905
Total Fat % : 25.8
Siri UWE Fat % : 20.0
Brozek UWE Fat % : 19.7
Soft Tissue Fat % : 27.0
% TBMC/FFM : 5.7

STD CV for Total BMD: 1.0 See Guide for other CVs.

4.5 x 9.0 mm, 90 mm/s, 62.10 cm Rev. 2.5.0 / 1.3.1 Calib. 05/31/96

COMMENTS
**ST. PAUL’S HOSPITAL  NUCLEAR MEDICINE DEPARTMENT**  
1081 Burrard St.  Vancouver, B.C. V6Z 1Y6 Ph. 631-5008

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**Change**  
**Short**  
**Long**  

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ST. PAUL'S HOSPITAL NUCLEAR MEDICINE DEPARTMENT
1081 Burrard St. Vancouver, B.C. V6Z 1Y6 Ph. 631-5008

Name
ID J6737
Age 18
Sex Female
Ethnic CAUCASIAN
Height 167.4
Weight 58.6

AP Spine 06/02/96 Sequence 1

Bone image not for diagnosis

<table>
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<table>
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| % Young Ref. | 88.8 |
| T - Score    | -0.80 |
| % Age Matched| ***** |
| Z - Score    | ***** |

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<th>%/Yr</th>
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<tr>
<td>L4 1.007</td>
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<tr>
<td>L2 - L4 1.034</td>
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STD CVs for L2-L4 BMD: 1.0 BMC: 1.5 See Guide for other CVs.
1.5 x 1.5 mm, 60 mm/s, 12.00 cm Rev. 2.5.0 / 1.3.1 Calib. 05/31/96

COMMENTS

301
### SCAN INFORMATION

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<td>RF</td>
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<td>Physician</td>
<td>BELZBERG</td>
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#### RESOLUTION
- **Resolution**: 1.5 x 1.5 mm
- **Speed**: 60 mm/s
- **Width**: 12.00 cm
- **Host/Scanner**: 2.5.0 / 1.3.1
- **Analysis Revision**: 2.5.0

### DETAILED RESULTS

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<th>BMC (g)</th>
<th>AREA (cm²)</th>
<th>LENGTH (cm)</th>
<th>WIDTH (cm)</th>
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<th>FAT MASS (g)</th>
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**Notes**:
- L2 Caucasian
- L3 Caucasian
- L4 Caucasian

**Graphs**:
- L2 Caucasian
- L3 Caucasian
- L4 Caucasian

**Scores**:
- T-Score
- Z-Score
- % Young Ref.
- % Age Matched

**Change**
- Short
- Long

**Percent Change**
- %/Yr
ST. PAUL'S HOSPITAL  NUCLEAR MEDICINE DEPARTMENT
1081 Burrard St.  Vancouver, B.C. V6Z 1Y6 Ph. 631-5008

<table>
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<tr>
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<tr>
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L H  Left Hip  06/02/96 Sequence 2

Bone image not for diagnosis

Fem Neck Caucasian
Norland 592(2.3)

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<th>% Age Matched</th>
<th>Z - Score</th>
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<td>*****</td>
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<td>12/04/94</td>
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Change %  Z/Yr
Short -2.5 -2.7
Long -2.2 -1.5

BMD

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<th>BMD</th>
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<td>4.423</td>
<td>1.50</td>
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<tr>
<td>Troch</td>
<td>0.773</td>
<td>9.060</td>
<td></td>
</tr>
<tr>
<td>Wards Tri</td>
<td>0.845</td>
<td>0.845</td>
<td>1.00</td>
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</table>

STD CVs for Neck BMD: 1.2  BMC: 1.7  See Guide for other CVs.
1.0 x 1.0 mm, 45 mm/s, 9.00 cm Rev. 2.5.0 / 1.3.1 Calib. 05/31/96

COMMENTS

303
ST. PAUL'S HOSPITAL  
NUCLEAR MEDICINE DEPARTMENT  
1081 Burrard St.  
Vancouver, B.C. V6Z 1Y6  
Ph. 631-5008

Name  
ID J6737
Address
Ethnic CAUCASIAN
Age 18
Menopause

Telephone  
days  
History  
eves  
Sex Female  
Height 167.4
Weight 58.4

Treatment

Medications

Comments

SCAN INFORMATION

Type Left Hip
Scan Date-Sec 06/02/96 2
Analysis Date 06/02/96
Calibration Date 05/31/96
Technician RF
Physician BELZBERG

Resolution 1.0 x 1.0 mm
Speed 45 mm/s
Width 9.00 cm
Host/Scanner 2.5.0 / 1.3.1
Analysis Revision 2.5.0

DETAILED RESULTS

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<td>g</td>
<td>cm²</td>
<td>cm</td>
<td>cm</td>
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<tr>
<td>Fem Neck</td>
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<td>4.423</td>
<td>4.67</td>
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<tr>
<td>Troch</td>
<td>0.773</td>
<td>9.060</td>
<td>11.71</td>
<td></td>
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<tr>
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<td>0.845</td>
<td>0.845</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
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</table>

Troch Caucasian Norland 592(2.3)  
Wards Tri Caucasian Norland 592(2.3)

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<th>Z - Score</th>
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<th>%/Yr</th>
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Change % %/Yr
short -1.6 -1.8  
Long -5.5 -5.7

*****
Guidelines for Keeping a Dietary Record

A dietary record is a detailed description of each food or beverage item eaten over a 24 hour time period. An accurately completed record can provide valuable information about the nutritional content of an individual’s usual diet. To assess your diet record correctly, we must be able to clearly picture the foods and beverages that you have record. The guidelines below will help you in recording accurate quantities and portion sizes of foods you have eaten.

Portion Size (Quantity):

Measure if you can. It may be helpful to measure how much your regular glasses, cups and bowls hold. You can describe portion sizes in many ways eg.:

- **volume**
  - 1 cup or 8 oz. or 250 ml of 2% milk
  - 1 tablespoon or 15 ml of peanut butter
  - 1 teaspoon or 5 ml of sugar

- **size**
  - 1-2" by 3/4" by 3/4" piece of cheddar cheese
  - 1 medium egg, poached
  - 1 small apple
  - 1 2" diameter digestive cookie
  - 1 medium bran muffin

- **weight**
  - 2 ounces or 60 grams of lean hamburger meat

- use labels on packages to help you
- see pictures below
1 teaspoon butter

8 oz (250 ml)

4 oz (125 ml)

1 medium muffin (100 grams)

1 medium apple (use this model to describe peaches, oranges, potatoes, tomatoes etc.)

chicken wing (1/2 oz lean flesh, 1/2 oz skin plus fat)

medium carrot 6" (15 cm)
1 ounce = 30 grams

1 hamburger pattie this thick = 3 ounces

1 hamburger pattie this thick = 2 ounces

1 slice of meat this thick = 3 ounces

2 slices of meat this thick = 3 ounces

cheese cube (1 oz)
(2"x3/4"x3/4")

chicken thigh and leg
3 ounces (90 grams)

hamburger pattie size

meat slice size
3-Day Dietary Analysis - Day 1

Date: ___________________________ Name: ___________________________

Time: __________________________ Food: ___________________________ Quantity: ___________________________
3-Day Dietary Analysis - Day 2

Date: _____________________ Name: _____________________

Time:     Food:                     Quantity:

______________________________
Appendix J.

Food Frequency Questionnaire
FOODS I EAT

We'd like to know about some of the foods you eat. For each food listed on the next page, please fill in how often you usually eat a portion of the size stated. If you eat the food:
- every day or more than once a day, fill in how many times you have it per day.
- less than once a day but more than once a week, fill in the times per week.
- less than once a week, but more than once a month, fill in the times per month.
- less often than once a month, or never eat it, put an "X" under "do not eat".

EXAMPLE: Janice has a glass of orange juice every morning, along with two slices of white toast. She usually has two sandwiches on brown bread at lunch, and eats french fries about three times a week. She almost never eats cauliflower.

<table>
<thead>
<tr>
<th>Food</th>
<th>Per day</th>
<th>Per week</th>
<th>Per month</th>
<th>Don't eat</th>
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</thead>
<tbody>
<tr>
<td>Orange juice, 1 cup</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>French fries, regular serving</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cauliflower, 1/2 cup (125 ml)</td>
<td></td>
<td>3</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Bread or toast, 1 slice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>white</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>brown</td>
<td>4</td>
<td></td>
<td></td>
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</table>

NUMBER OF TIMES I EAT THE FOOD

<table>
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<th>Food</th>
<th>Per day</th>
<th>Per week</th>
<th>Per month</th>
<th>Don't eat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bread or toast, 1 slice or 1 roll</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>white</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>brown</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muffin, 1 large</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pizza, 1 medium slice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheeseburger</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheese - 1 slice processed OR 1 piece</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hard cheese (plain or in sandwich)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broccoli, 1/2 cup (125 ml)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gai-lan (Chinese broccoli), 1/2 cup</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bok-choi (Chinese cabbage), 1/2 cup</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ice cream (large scoop)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item</td>
<td>Per day</td>
<td>Per week</td>
<td>Per month</td>
<td>Don't eat</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>---------</td>
<td>----------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Frozen yogurt (large scoop)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast food milkshake</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Cottage cheese, 1/2 cup (125 ml)</td>
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<tr>
<td>Yogurt, small (175 ml) carton or equivalent</td>
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<tr>
<td>Canned salmon or sardines with bones</td>
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<td></td>
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<td></td>
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<tr>
<td>Soft drink, regular, 1 can or large glass</td>
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<tr>
<td>Soft drink, diet, 1 can or large glass</td>
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<tr>
<td>Coffee or tea, 1 cup</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Tofu, 2 oz (60 gm)</td>
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<td>Milk on cereal</td>
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<tr>
<td>Orange juice, 1 cup</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Milk (any type including chocolate)</td>
<td></td>
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<tr>
<td>Macaroni &amp; cheese, 1 cup (250 ml)</td>
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</tbody>
</table>

I usually drink (choose one only):
- homo (whole) milk OR
- 2% milk OR
- 1% milk OR
- skim milk OR
- chocolate milk

Are you allergic to any foods?
- no
- yes: (specify: ______________________________)

Do you use any vitamin and/or mineral supplements?

<table>
<thead>
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<th>Supplement</th>
<th>Daily &gt;3x/week</th>
<th>1-3x/wk</th>
<th>&lt;1/wk</th>
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<td>Other</td>
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Appendix K.
PRECEDE PROCEED Model Application

Phase 1. - Social Diagnosis

Community Problems and (Presumed Causes):

- increasing aging population (better medical care, improved lifestyle)
- decreased aged population's quality of life (fractures causing loss of independence, pain, discomfort etc.)
- osteoporosis (poor lifestyle habits)
- osteoporotic fractures (low bone density)
- decreased fitness level and activity level of adolescents (less active, much time spent watching TV and playing video games)
- problems and barriers to exercise program participation and adherence (program, social, physical issues)

Priorities:

1. Increase adherence of adolescents to exercise programs.
2. Increase physical activity level of adolescents.
3. Increase bone density of adolescents.

Phase 2. - Epidemiological Diagnosis

Epidemiological Data:

- more than 800,000 Canadians are affected by osteoporosis (OSTOP, 1992)
- 1 in 4 women over age 65 in Canada suffer from osteoporosis (OSTOP, 1992)
- a predicted 72.8% increase from 1987-2006 in proximal femur fractures will amount to 22,922 women and 7,846 men being affected (Martin et al., 1991)
- 50% of people drop out of exercise programs within the first 6 months (Dishman, 1988; Naylor, 1992; Nicholas, et al., 1993; Noland, 1989)
- only <15% of females aged 10-14 years engage in moderate aerobic exercise for 30+ minutes every other day (Health and Welfare Canada, 1993; Stephens and Craig, 1990)
- 20% of females aged 10-14 years watch more than 15 hours of TV/week (Stephens and Craig, 1990)
- <15% of females aged 10-14 years smoke (Stephens and Craig, 1990)
- weight bearing exercise, especially weight training, increases bone density (Francis, 1990; Martin and Bailey, 1993; Woolf and Dixon, 1988)
- smoking, hormonal status, dietary practices affect bone density (Francis, 1990; Martin and Bailey, 1993; Woolf and Dixon, 1988)
- School health and physical education curriculum includes little information regarding bone health

*Risk Factors for Osteoporosis (low bone density)*: (Francis, 1990; Martin and Bailey, 1993; OSTOP, 1992; Woolf and Dixon, 1988)

**Genetic:**
- Caucasian or oriental (fair skin, small boned)
- History of osteoporosis in the family
- Early menopause
- Delayed menarche

**Personal:**
- Sedentary lifestyle
- Some medications
- Extreme endurance training
- Little knowledge in the area of bone density and osteoporosis and effects of certain lifestyle behaviours
- Smoking
- Delayed menarche

**Dietary:**
- Low intake of calcium rich foods
- Excessive intake of cola, tea or coffee per day
- Drink more than two alcoholic drinks per day
- Poor diet, low calorie, inadequate nutrients
- Eating disorders

**Program Goal:**

Bone mineral density of adolescent girls will be increased through regular participation in physical exercise and calcium supplementation.

**Health Objectives:**

1. Bone mineral density of adolescent girls will increase by 2-3% relative to controls after 18 months of participation in the exercise and calcium-supplementation program.

2. Adolescent girls will participate in the weight-training exercise program 80% of the scheduled 3x/wk exercise sessions.

3. Adolescent girls will become more aware of healthy lifestyle practices conducive to bone health.
Phase 3. - Behavioural and Environmental Diagnosis

5 Steps:

<table>
<thead>
<tr>
<th>Behavioural</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. personal factors</td>
<td>genetic factors</td>
</tr>
<tr>
<td>dietary factors</td>
<td>school curriculum</td>
</tr>
<tr>
<td></td>
<td>social influences</td>
</tr>
</tbody>
</table>

2. All factors are both preventive and treatment oriented. Genetic factors eliminated as possible targets.

3. & 4. Importance Changeability

**Behavioural Factors:**
- exercise: high, med.-high
- calcium intake: high, medium
- poor diet etc.: medium, medium
- delayed menarche: medium, low
- smoking: med.-low, med.-low
- alcohol: low, med.-low
- medications: low, low
- knowledge: high, high

**Environmental Factors:**
- school curriculum: medium, low
- social: medium, med.-low

5. more important less important

<table>
<thead>
<tr>
<th>more changeable</th>
<th>less changeable</th>
</tr>
</thead>
<tbody>
<tr>
<td>more important</td>
<td>less important</td>
</tr>
<tr>
<td>exercise</td>
<td>television</td>
</tr>
<tr>
<td>calcium</td>
<td>video games</td>
</tr>
<tr>
<td>knowledge</td>
<td></td>
</tr>
<tr>
<td>poor diet etc.</td>
<td>medications</td>
</tr>
<tr>
<td>smoking</td>
<td>alcohol</td>
</tr>
<tr>
<td>delayed menarche</td>
<td></td>
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</tbody>
</table>
Objectives:

By the end of the intervention program 80% of the subjects will have:

1. missed no more than 20% of the planned 3x/wk exercise sessions,
2. missed taking no more than 20% of the planned calcium supplementation.
3. made changes towards better overall dietary and lifestyle practices.
4. increased their knowledge in the area of healthy lifestyle practices, bone density and osteoporosis.

Note: Knowledge has been identified as a behaviour target for the intervention program, however, it will not be implemented into this research study as it could add another confounding variable. It is included though in the planning so it can be implemented in future health promotion programs if the results of this study prove positive.

Phase 4. - Behavioural and Environmental Diagnosis

<table>
<thead>
<tr>
<th>Factor</th>
<th>Importance</th>
<th>Changeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predisposing:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>knowledge:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- osteoporosis</td>
<td>med.-high</td>
<td>high</td>
</tr>
<tr>
<td>- bone density</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>- effects of lifestyle</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>attitudes:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- regular exercise</td>
<td>high</td>
<td>low-med.</td>
</tr>
<tr>
<td>- weight-training</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>- healthy diet</td>
<td>high</td>
<td>low-med.</td>
</tr>
<tr>
<td>- healthy body weight</td>
<td>medium</td>
<td>low-med.</td>
</tr>
<tr>
<td>- smoking/alcohol</td>
<td>low</td>
<td>low-med.</td>
</tr>
<tr>
<td>values:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- physical activity</td>
<td>medium</td>
<td>low-med.</td>
</tr>
<tr>
<td>- quality of life</td>
<td>medium</td>
<td>low-med.</td>
</tr>
<tr>
<td>- feeling of well-being</td>
<td>medium</td>
<td>low-med.</td>
</tr>
</tbody>
</table>

table continued next page
<table>
<thead>
<tr>
<th>Factor</th>
<th>Importance</th>
<th>Changeability</th>
</tr>
</thead>
<tbody>
<tr>
<td>beliefs:</td>
<td>weight training will increase bone density</td>
<td>medium</td>
</tr>
<tr>
<td></td>
<td>bone density will decrease osteoporosis</td>
<td>medium</td>
</tr>
<tr>
<td></td>
<td>regular exercise is necessary to increase bone density</td>
<td>medium</td>
</tr>
<tr>
<td></td>
<td>exercise will increase feelings of well-being</td>
<td>medium</td>
</tr>
<tr>
<td></td>
<td>calcium supplements will increase bone density</td>
<td>medium</td>
</tr>
<tr>
<td>personal:</td>
<td>self-efficacy</td>
<td>med.-high</td>
</tr>
<tr>
<td></td>
<td>motivation</td>
<td>med.-high</td>
</tr>
<tr>
<td></td>
<td>previous activity</td>
<td>med.-low</td>
</tr>
<tr>
<td></td>
<td>body weight/image</td>
<td>medium</td>
</tr>
<tr>
<td></td>
<td>perceived time</td>
<td>high</td>
</tr>
</tbody>
</table>

**Enabling:**

| program: | activity, intensity, duration (moderate) | medium | medium |
| | choice of activity | medium | low-med. |
| | flexibility | medium | med.-low |
| | convenience | med.-high | high |
| | skill training | medium | high |
| | use of behavioural/cognitive models | med.-high | high |
| resources: | time/money | high | low-med. |
| | school, teacher, parental support | high | medium |
| | leadership | high | medium |
table continued from previous page

<table>
<thead>
<tr>
<th>Factor</th>
<th>Importance</th>
<th>Changeability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reinforcing:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>physical:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- increased feelings of well-being</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>- increased strength, bone density, muscle tone</td>
<td>med.-high</td>
<td>med.-high</td>
</tr>
<tr>
<td>- increased skills and knowledge</td>
<td>medium</td>
<td>high</td>
</tr>
<tr>
<td>emotional:</td>
<td></td>
<td>med.-high</td>
</tr>
<tr>
<td>- increased self-efficacy</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>- feedback (social support)</td>
<td>med.-high</td>
<td>med.-high</td>
</tr>
<tr>
<td>- enjoyment</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>- social experiences</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>tangible:</td>
<td></td>
<td>med.-high</td>
</tr>
<tr>
<td>- incentives</td>
<td>high</td>
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</tbody>
</table>

**Priorities:**

Enabling factors are given first priority followed by one of the predisposing factors; knowledge. Reinforcing factors, and the remainder of the predisposing factors are given next priority.

**Phase 5. - Administrative and Policy Diagnosis**

**Resources Needed:**

- time (3-40 min. sessions/week)
- personnel (supervisor/investigator)
- facilities (weight-training equipment)
- money (measurements, incentives etc.)

**Resources Available:**

All the needed resources were available. Students had free blocks during their school timetable as well as before or after school. A research grant from the Canadian and Fitness Lifestyle Research Institute provided money for testing.
and incentive prizes. All schools had a weight room and membership fees for the weight training club provided money for equipment repair and new equipment. Grade 12 Physical Education students acted as weight room supervisors and were trained for the positions and received course credit for their time and efforts.

Possible Barriers:

i) staff time/commitment
ii) staff attitudes towards program
iii) goal conflict
iv) familiarity/complexity of program
v) space
vi) community barriers (e.g., no parental or school district support)
vii) school program/curriculum conflicts/limitations
viii) not envisioning benefits to school etc.

Solutions to Barriers:

i) - program will be part of subjects' regular scheduled school day during free time so as to not interfere with classes or increase demand on teachers
   - teachers at the different schools were asked about their interest in the program and only those who were interested and willing to participate were asked to assist

ii) - information packages about the program and benefits to students, staff and the schools were given to participating schools

iii) - this program contributes to the physical and health education goal of developing knowledge and competence to meet the demands of daily and healthy living

iv) - the program is straightforward, well planned with information and training sessions, log books with diagrams and open lines of communication between participants and the investigator

v) - only a weight room is required for space with limited equipment, which is standard in most schools
   - flexibility in the program will allow for adaptations to slightly different spaces or equipment at different schools

vi) - the school district representatives, teachers, and parents of potential subjects were invited to an informational meeting to explain the program and its benefits
- the district was also made aware that it would create no extra work or support from them
- parents were included in all formal communication to their daughters about the study and invited to attend testing and some social sessions for the subjects
- a reciprocal relationship was set up with the community centers who provided incentive prizes for the subjects in exchange for encouraging students to exercise at the community center

vii) - the program was consistent with the goal of comprehensive school health and fit into the regular school curriculum

viii) - information packages, introductory letters to the school board, teachers and parents and the introductory information meeting clearly outlined the numerous benefits to all of implementing the health promotion program.

Phase 6. - Implementation

Details of the Intervention Program:

Overview

Time: January 1995 - June 1996
3 - 40 minute sessions per week during school hours
Place: local high school weight rooms
Activity: weight-training exercises, to task all major muscle groups, of moderate to high intensity (65-85% 1 rep. max.)

Attention to Factors:

Predisposing

Students, school personnel and parents will received information packages and an introductory presentation to learn about the program and its benefits. Educational pamphlets and monthly health education/social sessions on bone density and related issues, goal setting and time management, will be presented to students involved in the program.

Enabling

A training session for both teachers and students was held at the start of the program so use of the equipment and proper exercise technique was learned. A
variety of exercises were introduced throughout the program to allow for some choice. Exercises were of moderate to high intensity with periodization and breaks from training and done right at the students' school. Frequent interaction with and feedback from the principle investigator as well as continuous feedback from the teacher/supervisor was given. Incentives and mini challenges with prizes for students were included. Goal setting, self contracts, and self monitoring with log books were some of the behavioral/cognitive strategies used.

Reinforcing

Students will exercise in groups and with friends, and have a buddy system to motivate each other. Social functions for the group will be organized. Log books showing weight lifted and repetitions completed and measurements of strength, diet, and lifestyle were done on an ongoing basis to show improvements. Opportunity for suggestions and comments were made available through open lines of communication to develop a sense of ownership of the program for the students. Hopefully enjoyment was facilitated through the social aspects and mini challenges, and peer support and feelings of well-being etc. Reports and updates to the subjects, schools, school district administration and parents illustrating the progress and benefits of the program were given to encourage continued support for the program.

Phase 7. - Process Evaluation

Ongoing process evaluation of the program was executed through informal and regular communication with school administrative and physical education staff as well as with subjects and program assistants. In person conversations, meetings, telephone calls and a suggestion box were some of the methods used to continually adapt program logistics to make it run efficiently, enhance compliance and be as enjoyable as possible for the subjects.

Phase 8. - Impact Evaluation

A questionnaire about factors affecting program compliance and what was learned by participating in the program was administered at the end of the program. Records of physical activity, calcium intake, dietary intake and weight-training were used to indicate compliance with the program.
Phase 9. - Outcome Evaluation

Post-program measures of bone mineral density, content and size will be used to indicate if subjects gained bone mineral above that gained in normal growth and if so, would act as a protective factor against osteoporosis.
Appendix L.  
Weight-Training Program

Training Principles:

Frequency - 3 days per week, alternate days to allow rest days in between.

Intensity - 65-85% of 1 repetition maximum; easy, moderate, high intensity weeks

Time - 1 set of 12-15 repetitions for each of the 10 exercises (easy)
2 sets of 8-10 repetitions for each of the 10 exercises (moderate)
3 sets of 5-7 repetitions for each of the 10 exercises (high)

Type - resistance-type exercises using machines, free weights, and body weight. Workouts 1 and 2 indicated below were alternated each workout session. The following exercises were included:

Workout 1:  
squats  
bench press  
hamstring curl  
shoulder press  
lunge  
seated row  
biceps curl  
calf press (or raises)  
abdominal crunches  
leg raises  

Workout 2:  
leg press  
stiff-legged dead lift  
incline shoulder press  
step-ups  
upright row  
lat pulldown  
triceps press (or extension)  
calf press (or raises)  
abdominal crunches  
leg raises

- alternate exercises were introduced for variety and options given when subjects were away on holidays or doing some training at home

Progression:

- 1 repetition maximums (1RM) were determined
- subjects first went through an orientation session to learn how to use the equipment and do the exercises properly and safely
- subjects started out at 65% of 1RM for 2 weeks to get used to the training program prior to the actual start of the program
- subjects completed exercises so the last three repetitions of each set were quite challenging
- weight was progressively increased when subjects were able to complete the last 3 repetitions of each set easily
- exercise substitutions for variety were introduced by the investigator or assistant
- the weight room was supervised at all times by trained grade 12 weight room attendants, the investigator, assistant, or school physical education teachers
- record sheets of exercises and weight lifted were completed by each subject during each exercise session
- periodic training sessions were held with the subjects to reiterate important training points on technique and progressions and to introduce alternate exercises for variety
- training information and schedules were posted on the weight room bulletin board

Periodization:

Subjects followed a 5 week cycle where week one was considered an easy intensity week, week 2 a moderate intensity week and weeks 3, 4 and 5 were high intensity weeks. This cycle was followed for the duration of the study with a week break every 3 months and one three week break in the middle of the study.

Warm Up and Cool Down:

A proper warm up and cool down of 7-10 minutes was done at the start and finish of each exercise session. This involved an easy run, cycle, stair climb, row, or calisthenics to gradually increase body temperature and heart rate. Stretches of all major muscle groups followed. The cool down included a low intensity aerobic type exercise followed by stretches held for 30-60 seconds for each muscle and joint.

(Fox et al., 1989; McArdle et al., 1995)
Appendix M.
"No Bones About It!" Program Questionnaire

Part A.

1. How much did each of the following affect your initial decision to sign up for the "No Bones" study?

(circle the appropriate number for each 1 = not at all 2 = very little 3 = somewhat 4 = quite a bit 5 = very much)

a) your interest in bones and osteoporosis
1 2 3 4 5
b) your friend(s) were doing it
1 2 3 4 5
c) your knowledge of the health risks for osteoporosis
1 2 3 4 5
d) parental influence
1 2 3 4 5
e) opportunity to participate in and learn about weight training
1 2 3 4 5
f) program sounded fun and interesting
1 2 3 4 5
g) other: ____________________________
1 2 3 4 5

2. What did you like the best about being in the "No Bones About It" program?
________________________________________

3. What did you like the least about being in the "No Bones About It" program?
________________________________________

4. What is the most important thing you learned from being a participant in this program?
________________________________________

5. Do you plan to come to the study end celebration on Thurs. June 6 at 7 pm at Handsworth School? (please circle) No Unsure Yes
Part B.

1. How did each of the following affect (either help or hinder) you in taking the calcium/placebo pills? 
   (circle the appropriate number for each 1 = big hindrance 2 = mild hindrance 3 = no effect 4 = mildly helpful 5 = big help)

   a) large size of the pill  
   b) thinking you were taking a placebo  
   c) believing that the calcium would help your bones  
   d) believing that the calcium would not help your bones  
   e) obligation to the study  
   f) forgetfulness  
   g) triggers/reminders/situation at home to help you remember  
   h) your motivation level  
   i) your feelings or belief in taking vitamin supplements in general  
   j) reminders from Sally  
   k) other: ________________________________

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<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
</table>
   a) | 1 | 2 | 3 | 4 | 5 |
   b) | 1 | 2 | 3 | 4 | 5 |
   c) | 1 | 2 | 3 | 4 | 5 |
   d) | 1 | 2 | 3 | 4 | 5 |
   e) | 1 | 2 | 3 | 4 | 5 |
   f) | 1 | 2 | 3 | 4 | 5 |
   g) | 1 | 2 | 3 | 4 | 5 |
   h) | 1 | 2 | 3 | 4 | 5 |
   i) | 1 | 2 | 3 | 4 | 5 |
   j) | 1 | 2 | 3 | 4 | 5 |
   k) | 1 | 2 | 3 | 4 | 5 |

2. How did each of the following affect (either help or hinder) you in keeping your physical activity, calcium and menstrual records? 
   (circle the appropriate number using the same scale as above)

   a) your motivational level  
   b) forgetfulness  
   c) obligation to the study  
   d) time consuming  
   e) understanding of the reason why they needed to be done  
   f) reminders from Sally  
   g) set up at home to help you remember or to make it a part of your routine  
   h) the social events and prizes  
   i) having the bone scan and nutritional analysis done  
   j) other: ________________________________

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<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
</table>
   a) | 1 | 2 | 3 | 4 | 5 |
   b) | 1 | 2 | 3 | 4 | 5 |
   c) | 1 | 2 | 3 | 4 | 5 |
   d) | 1 | 2 | 3 | 4 | 5 |
   e) | 1 | 2 | 3 | 4 | 5 |
   f) | 1 | 2 | 3 | 4 | 5 |
   g) | 1 | 2 | 3 | 4 | 5 |
   h) | 1 | 2 | 3 | 4 | 5 |
   i) | 1 | 2 | 3 | 4 | 5 |
   j) | 1 | 2 | 3 | 4 | 5 |
Part C. only weight-trainers answer this part; non weight-trainers go to part D.

1. How did each of the following affect (either help or hinder) your ability to continue with the regular weight-training for the 18 month program? (circle the appropriate number for each using the same scale as the previous questions 1 = big hindrance 2 = mild hindrance 3 = no effect 4 = mildly helpful 5 = big help)

   a) your interest level in the program
   b) desire to become stronger and more toned
   c) desire to enhance other sport performance
   d) time consuming
   e) other school commitments
   f) other family or extracurricular obligations
   g) the actual program (eg., variety, intensity, specific exercises)
   h) the weight room atmosphere
   i) encouragement from Sally, Jen and Andrea
   j) "Stars of the Month"
   k) the weight room equipment
   l) the social events and prizes
   m) knowledge of the benefits of exercise for healthy bones
   n) influence from friends or family
   o) a challenge for you; a new goal to reach
   p) having the bone scan and nutritional analysis done
   q) other: ____________________________

Part D. non weight-training subjects fill this part out and weight-trainers answer question 2 only.

1. Would you come to a session with the other non weight-training subjects in the study for a educational session in your school weight room on how to weight train properly and a demonstration of equipment use?  Yes  No

2. Is there anything else you would like to get out of this study (remember you will be getting a copy and interpretation of all your bone scans, measurements and nutritional analysis)? If yes, please indicate what:

________________________________________________________________________

________________________________________________________________________
Appendix M-b
"No Bones About It!" Program Questionnaire
Compliance Factor Results

Means and standard deviations for each of the factors for each question are reported along with the rank order of importance for each factor for each question. The factors having the most influence or importance for compliance are noted with * corresponding to the higher ranking means e.g., 1, 2, 3. The factors which had the most hindering influence on compliance are noted with ** and correspond to lower ranking means, e.g., 5, 6, 14, 15.

Part A.

1. How much did each of the following affect your initial decision to sign up for the "No Bones" study?

<table>
<thead>
<tr>
<th>Factor</th>
<th>Mean</th>
<th>SD</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) your interest in bones and osteoporosis</td>
<td>2.8</td>
<td>0.9</td>
<td>5 **</td>
</tr>
<tr>
<td>b) your friend(s) were doing it</td>
<td>2.2</td>
<td>1.3</td>
<td>6 **</td>
</tr>
<tr>
<td>c) your knowledge of the health risks for osteoporosis</td>
<td>2.9</td>
<td>1.1</td>
<td>3</td>
</tr>
<tr>
<td>d) parental influence</td>
<td>2.8</td>
<td>1.4</td>
<td>4</td>
</tr>
<tr>
<td>e) opportunity to participate in and learn about weight training</td>
<td>3.5</td>
<td>1.1</td>
<td>2 *</td>
</tr>
<tr>
<td>f) program sounded fun and interesting</td>
<td>3.6</td>
<td>0.9</td>
<td>1 *</td>
</tr>
</tbody>
</table>

2. What did you like the best about being in the "No Bones About It" program?

- learning more about the body, bones, health and osteoporosis
- getting stronger and seeing the change over the 18 months
- social aspects
- getting the bone scan and nutritional analysis done

3. What did you like the least about being in the "No Bones About It" program?

- keeping the records
- program length
- taking the pills
- time consuming
4. What is the most important thing you learned from being a participant in this program?

- importance of healthy eating and exercise
- osteoporosis prevention
- how to weight train
- responsibility and dedication

Part B.

1. How did each of the following affect (either help or hinder) you in taking the calcium/placebo pills?

1 = big hindrance  2 = mild hindrance  3 = no effect  4 = mildly helpful  5 = big help

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>SD</th>
<th>rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) large size of the pill</td>
<td>2.7</td>
<td>0.6</td>
<td>8 **</td>
</tr>
<tr>
<td>b) thinking you were taking a placebo</td>
<td>2.6</td>
<td>0.7</td>
<td>9 **</td>
</tr>
<tr>
<td>c) believing that the calcium would help your bones</td>
<td>4.1</td>
<td>0.8</td>
<td>1 *</td>
</tr>
<tr>
<td>d) believing that the calcium would not help your bones</td>
<td>2.8</td>
<td>0.6</td>
<td>7</td>
</tr>
<tr>
<td>e) obligation to the study</td>
<td>3.8</td>
<td>1.1</td>
<td>3 *</td>
</tr>
<tr>
<td>f) forgetfulness</td>
<td>2.1</td>
<td>1.1</td>
<td>10 **</td>
</tr>
<tr>
<td>g) triggers/reminders/situation at home to help you remember</td>
<td>3.6</td>
<td>1.0</td>
<td>4</td>
</tr>
<tr>
<td>h) your motivation level</td>
<td>3.4</td>
<td>1.0</td>
<td>6</td>
</tr>
<tr>
<td>i) your feelings or belief in taking vitamin supplements in general</td>
<td>3.5</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>j) reminders from Sally</td>
<td>3.9</td>
<td>0.8</td>
<td>2 *</td>
</tr>
</tbody>
</table>

2. How did each of the following affect (either help or hinder) you in keeping your physical activity, calcium and menstrual records? (same scale as for above question)

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>SD</th>
<th>rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) your motivational level</td>
<td>3.3</td>
<td>1.1</td>
<td>7</td>
</tr>
<tr>
<td>b) forgetfulness</td>
<td>2.0</td>
<td>0.9</td>
<td>9 **</td>
</tr>
<tr>
<td>c) obligation to the study</td>
<td>3.8</td>
<td>0.9</td>
<td>3</td>
</tr>
<tr>
<td>d) time consuming</td>
<td>2.3</td>
<td>0.8</td>
<td>8 **</td>
</tr>
<tr>
<td>e) understanding of the reason why they needed to be done</td>
<td>3.6</td>
<td>0.9</td>
<td>4</td>
</tr>
<tr>
<td>f) reminders from Sally</td>
<td>3.9</td>
<td>0.8</td>
<td>2 *</td>
</tr>
<tr>
<td>g) set up at home to help you remember or to make it a part of your routine</td>
<td>3.4</td>
<td>1.0</td>
<td>6</td>
</tr>
</tbody>
</table>
h) the social events and prizes & 3.5 & 0.8 & 5 \\
i) having the bone scan and nutritional analysis done & 4.1 & 0.9 & 1* \\

**Part C.**

1. How did each of the following affect (either help or hinder) your ability to continue with the regular weight-training for the 18 month program?
1 = big hindrance    2 = mild hindrance    3 = no effect
4 = mildly helpful    5 = big help

| a) your interest level in the program | 3.6 | 1.0 | 9 |
| b) desire to become stronger and more toned | 4.4 | 0.7 | 1* |
| c) desire to enhance other sport performance | 4.1 | 0.7 | 3* |
| d) time consuming | 1.6 | 0.9 | 16** |
| e) other school commitments | 2.0 | 0.8 | 15** |
| f) other family or extracurricular obligations | 2.2 | 1.0 | 14** |
| g) the actual program (eg., variety, intensity, specific exercises) | 3.2 | 0.8 | 11 |
| h) the weight room atmosphere | 2.7 | 0.8 | 13** |
| i) encouragement from Sally, Jen and Andrea | 3.9 | 0.7 | 4* |
| j) "Stars of the Month" | 3.6 | 0.9 | 8 |
| k) the weight room equipment | 2.9 | 0.8 | 12 |
| l) the social events and prizes | 3.8 | 0.7 | 7 |
| m) knowledge of the benefits of exercise for healthy bones | 4.3 | 0.7 | 2* |
| n) influence from friends or family | 3.5 | 0.8 | 10 |
| o) a challenge for you; a new goal to reach | 3.9 | 0.6 | 4* |
| p) having the bone scan and nutritional analysis done | 3.8 | 0.8 | 6 |
Appendix N.

Weight-Training Record Sheet
<table>
<thead>
<tr>
<th>Exercise</th>
<th>Reps</th>
<th>Sets</th>
<th>WT</th>
<th>VT</th>
<th>ST</th>
<th>TJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg Raises</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross Overs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdominal Crunch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Car (Press)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension Press</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulldown (Lift)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upright</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step-Ups</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shoulder Press</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dead Lift</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg Press</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix O.
Physical Activity Record Instructions

Keeping Track of Your Physical Activity

Find a journal, notebook or calendar with big enough boxes or space to write a few lines. Each day you do physical activity record it in your journal.

Note: do not record Physical Education classes or walking to or from school.

Record 4 things on the days you are active:

1. the date (if you are not using a calendar)
2. the type of activity you did (eg. swim, run, bike etc.)
3. how long you did the activity for (eg. 20 minutes)
4. how intense or tiring the activity was; choose the number on the following scale that best describes your activity:

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>7</td>
<td>15=hard</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>17=very hard</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>11</td>
<td>19=very, very hard</td>
</tr>
<tr>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>13</td>
<td>somewhat hard</td>
</tr>
</tbody>
</table>

Keep your journal on your desk or with your school daytimer or in someplace that you will remember to fill it out regularly (keep it with your calcium record sheet). This record is important to determine how much, if any, physical activity contributes to changes in bone density. Please be as accurate and honest as possible. Leave dates blank where no physical activity was done.
Appendix P.
Incentive Program Summary

Educational and Social Get-Togethers:

- meetings were held at each school for all the subjects at that school approximately once every two months for personal contact, enhance the sense of being part of the program and to deliver calcium supplements or other program information
- special theme social get togethers were held 4 times throughout the program which gave all the participants from all schools a chance to meet each other, snack on healthy homemade baking, refreshments etc., learn something related to their health, receive incentive prizes and program information
  a) May 29, 1995 - Healthy Desserts theme
     - health education included review of nutritional analysis and basic healthy eating guidelines
  b) Dec. 4, 1995 - Christmas Celebration theme
     - health education included a film on self esteem, self confidence and eating disorders
  c) Mar. 11, 1996 - maximizing your benefits of participation theme
     - health education component was divided into two groups; training tips and healthy habits for teenage girls
  d) Jun. 6, 1996 - Study End Celebration theme
     - health education component included tips for healthy bones and healthy lifestyles (see attachment A)

Weight-Training:

- school weight room was painted, rearranged and redecorated
- a school weight-training club was formed and participants received free membership
- an information board dedicated to the participants was put up with continuous new information displayed of program oriented, participant recognition, and motivational materials
- personal instruction on how to weight train
- weight-training attendance summaries mailed out to participants as a reminder
- training assistants held group weight-training sessions giving constant feedback re proper technique and encouragement
- option of training at a community weight room during the summer
- personal weight-training information and log book for all weight trainers
- periodic strength tests to show improvements
Participant Recognition and Incentive Prizes:

- the program was given a "catchy" name, "No Bones About It!" and all subjects and study activities were referred to by this
- names of participants in school newsletters (see attachment B)
- display boards with names and pictures in school hallways
- school program representatives were elected/volunteered
- letters of thanks and certificates of appreciation (see attachment C) awarded at the end of the study
- "Stars of the Month" - subjects' names up on school display board, in school newsletters and prizes were awarded for consistent weight-training participation (see attachment D)
- subjects who kept the best records, had the highest supplementation compliance, and weight-training attendance were awarded prizes at the end of the study at the study celebration
- a program T-shirt logo design contest was held with all participants being able to vote
- all subjects received a program T-shirt
- all subjects received a grab bag of prizes at the study end celebration
- prizes ranged from beauty products, gift certificates, active wear clothes, community fitness passes and memberships, earrings etc.

Personal Contact and Encouragement

- frequent newsletters (e.g., see attachment E and F) and personal phone contact (at least 2x/month) was made with all subjects to inform them of program events and also to discuss with them personally their involvement, progress, questions, concerns, and to encourage and thank them for their ongoing participation
- the testing sessions were set up so again the subject was in a non-threatening environment to discuss any questions or concerns
- an effort was made to talk with each subject at the social get togethers

Personal Results

- all subjects received a copy of their first whole body DXA scan printout with interpretation of the results
- all subjects received a detailed nutritional analysis of their first 3-day food record with interpretation and some basic healthy dietary guidelines (attachment G)
- all subjects received a comparison of all their measurement results from the three measurement sessions (attachment H)
- all subjects will receive a summary of the overall results of the study
"No Bones About It" ..... the study is over but the beneficial effects have the potential to last you a lifetime! I hope that you value the experience of being involved in this study and realize your important contribution to a very key health issue. Osteoporosis is a disease of progressive bone loss leading to low bone mass which results in very fragile bones susceptible to fracture. Think of the pain, disability and decreased quality of life trying to walk around with crushed, fractured bones. It mostly affects older women but you will be one too someday and what you do now greatly affects the quality of your life today and when you are older. Many teenagers are putting themselves at greater risk for early and/or more severe osteoporosis, as well as other illnesses because of poor lifestyle habits. From this study and previous research many recommendations are provided to help teenagers develop strong healthy bones while growing .... the most critical time for laying down bone mass!!! Once you are an adult your potential for increasing bone mass is very very limited. Keep in mind the following recommendations, which not only help keep your bones healthy, but the rest of you as well!

1. Make a lifelong commitment to regular weight bearing physical exercise like weight training, hiking, jumping, cross training etc. A variety of vigorous short duration activities are best. Activities that increase muscle strength and work all large muscle groups are encouraged.

2. Avoid periods of immobility; even brief daily weight-bearing movements can help conserve bone during sickness or injury.

3. Eat a well balanced diet to ensure meeting the recommended intake of all nutrients but especially calories, protein, carbohydrates and calcium. Disordered eating habits, including restrictive eating, calorie reduced diets, limited variety diets (eg. strict vegan) may result in a permanent deficit in bone throughout one's life.

4. Avoid situations of menstrual dysfunction because the hormone estrogen is very important for absorption of calcium into bone. Loss of, or irregular periods or delayed onset of periods, caused by excessive exercise, weight loss, stress etc. or a combination, represent a potential major hazard to your bones. Restore energy balance and menstrual normalcy as quickly as possible.

Tips for Healthy Bones
5. Avoid cigarettes because they affect estrogen levels and, therefore, may cause bone loss at any age.

6. Avoid excess amounts of caffeine, colas (especially diet), and alcohol because they affect the absorption of calcium into bone and/or promote the breakdown of bone.

All of the above recommendations are interrelated, meaning by following just one of them will not be enough to develop and maintain strong bones. Strive for your optimal situation possible for all of the recommendations. Tell your friends and your mom about them too!

** You will get a summary of the study findings, along with your individual results, mailed to you within a few months time.

### Table 1. Optimal Calcium Requirements

<table>
<thead>
<tr>
<th>Group</th>
<th>Optimal Daily Intake (in mg of calcium)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infants</td>
<td></td>
</tr>
<tr>
<td>Birth–6 months</td>
<td>400</td>
</tr>
<tr>
<td>6 months–1 year</td>
<td>600</td>
</tr>
<tr>
<td>Children</td>
<td></td>
</tr>
<tr>
<td>1–5 years</td>
<td>800</td>
</tr>
<tr>
<td>6–10 years</td>
<td>800–1,200</td>
</tr>
<tr>
<td>Adolescents/Young Adults</td>
<td></td>
</tr>
<tr>
<td>11–24 years</td>
<td>1,200–1,500</td>
</tr>
<tr>
<td>Men</td>
<td></td>
</tr>
<tr>
<td>25–65 years</td>
<td>1,000</td>
</tr>
<tr>
<td>Over 65 years</td>
<td>1,500</td>
</tr>
<tr>
<td>Women</td>
<td></td>
</tr>
<tr>
<td>25–50 years</td>
<td>1,000</td>
</tr>
<tr>
<td>Over 50 years (postmenopausal)</td>
<td></td>
</tr>
<tr>
<td>On estrogens</td>
<td>1,000</td>
</tr>
<tr>
<td>Not on estrogens</td>
<td>1,500</td>
</tr>
<tr>
<td>Over 65 years</td>
<td>1,500</td>
</tr>
<tr>
<td>Pregnant and nursing</td>
<td>1,200–1,500</td>
</tr>
</tbody>
</table>
*** Please include in the December issue of the school newsletter. Thank you! Please let me know if there is any concern or if this cannot be included.

"No Bones About It!"

Yes - no bones about it! The osteoporosis prevention study which is being carried out at the school by researchers from UBC is well underway. About 20 Windsor female students have volunteered their interest, time and effort to participate in this unique opportunity. Over the last month they have been involved in measurement sessions including muscle strength testing, body composition and nutritional analysis, as well as bone density testing at St. Paul's Hospital. These girls are part of the Calcium/Lifestyle Control group of the study and starting in January will start the year program of calcium or placebo supplementation and lifestyle monitoring. The girls will have lots of learning opportunities in the area of lifestyle and bone health and enjoy incentives for their participation. A big thank you and lots of encouragement to our participants:

BETH  KRISTI
LISA   AMANDA
CATHERINE MICHELLE
ALISON  JOYCE
KATRINA MELANIE
JESSICA YOUN JIN
LEAH  SHARON
CAROLINE CHRISTINA
KRISTEN  ALISON
BIANCA  LARA

340
"NO BONES ABOUT IT"

CERTIFICATE OF PARTICIPATION

This certifies that

has been a valuable participant
in the 18 month research study on bone health.

UBC SCHOOL OF HUMAN KINETICS

Researcher ___________________________ Date ___________________________
"No Bones About It!" Research Study Update

The bone research study continues with the great efforts of the 65 Handsworth girls participating. The faithful weight-trainers are feeling the strength benefits and more! Strength testing was held in early April and the improvements are great! The girls listed below are members of the "Stars of the Month" club - these are the ones who have barely missed any of their 3x/wk weight-training sessions! Congratulations to you all for your commitment and determination! For the month of March we welcome some new members:

Annie          Sabrina          Nadine
Shonagh        Liz              Kim
Amy

Consistent members from January include:

Kim            Monique          Danielle
Nicole         Joy              Chelsea
Audrey         Shannon          Sarah
Amy            Jane             Kristine
Caroline       Alana            Sonja

All these girls will be receiving incentive prizes soon for their participation. We need to see all the weight-training girls on this list so keep working at it!!!!

A T-shirt design contest is underway right now to design a logo for the study and the T-shirts which all study participants will receive at the 6 month point of the study.

****Remember designs must be in to me by May 5th!!
'No Bones' study update...

- three months to go!
- final testing in the hospital will take place between Apr. 26 and June 7 (Sat/Sundays, Tues. late afternoons and some Fridays)
- final strength testing is tentatively scheduled for:
  - Handsworth: Wed. May 22 - 8:15am or Thurs. May 23 - 3:00pm
  - Sentinel: Thurs. May 23 - 12 noon
  - Windsor: Fri. May 24 - 8:00am
  - Argyle: Fri. May 24 - 12 noon
- please mark your date - attendance is absolutely mandatory *so let Sally know if you cannot attend this time
- the final study celebration is on Thurs. June 6 - 7:00pm!! *mark the date* - prizes, fun, rewards for dedication, study results, and a big thank-you!! !I don’t miss it!!
- please keep all your records - you will hand them in to Sally at either of your final testing sessions - they are very important to the study results - without them we have nothing
- there will be a few questionnaires and a three-day food record to complete during your final testing
- you will get detailed results and what they mean to your health

*maintain your cool ~

take your calcium pills!

- keep taking that calcium, doing your weight training and keeping your records!

-do it for your health, a sense of responsibility to yourself, for enjoyment & learning, and to feel great-

-I appreciate your dedication to the study-
thank-you

nutritional tips for women...

- Good nutrition plays a role in: health, appearance, laying down foundation for healthy bones and a base for healthy childbearing
- yet Nutrition Canada depicts adolescent girls as poorly nourished (The Complete Cdn Health Guide) and notes a shortage of the following:
  - calcium
  - iron
  - Vitamin D
  - folic acid
- young women should aim to eat more healthfully!!
- calcium is of particular importance in the protection against osteoporosis, a bone disorder that affects 1.4 million Cdns over the age of 50 - the majority being women

"Osteoporosis is a preventable/treatable condition and is not an inevitable consequence of the aging process"

- plan now; instil healthy habits while you're young to ensure optimal functioning and quality living through later years
### Recommended Nutrient Intakes

<table>
<thead>
<tr>
<th>Name:</th>
<th>Age: 15 yrs.</th>
<th>Sex: Female</th>
<th>Moderately Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight: 55.6 kg.</td>
<td>Height: 167 cm.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Intake</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calories</td>
<td>2200</td>
<td>*</td>
</tr>
<tr>
<td>Protein</td>
<td>53.4 G</td>
<td>Vitamin B6 0.801 Mg</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>319 G</td>
<td>Vitamin B12 1.0 Mg</td>
</tr>
<tr>
<td>Dietary Fiber</td>
<td>22 G</td>
<td>Folacin 172 Mcg</td>
</tr>
<tr>
<td>Fat-Total</td>
<td>73.3 G</td>
<td>Pantothenic 7 Mg</td>
</tr>
<tr>
<td>Fat-Saturated</td>
<td>24.4 G</td>
<td>Vitamin C 30 Mg</td>
</tr>
<tr>
<td>Fat-Mono</td>
<td>24.4 G</td>
<td>Vitamin E 7 Mg</td>
</tr>
<tr>
<td>Fat-Poly</td>
<td>24.4 G</td>
<td>Calcium 1000 Mg</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>300 Mg</td>
<td>Copper 2.5 Mg *</td>
</tr>
<tr>
<td>Vit A-Carotene</td>
<td>RE</td>
<td>Iron 13 Mg</td>
</tr>
<tr>
<td>Vit A-Preformed</td>
<td>RE</td>
<td>Magnesium 180 Mg</td>
</tr>
<tr>
<td>Vit A-Total</td>
<td>800 RE</td>
<td>Magnesium 180 Mg</td>
</tr>
<tr>
<td>Thiamin-B1</td>
<td>0.88 Mg</td>
<td>Magnesium 180 Mg</td>
</tr>
<tr>
<td>Riboflavin-B2</td>
<td>1.1 Mg</td>
<td>Potassium 3892 Mg *</td>
</tr>
<tr>
<td>Niacin-B3</td>
<td>15.8 Mg</td>
<td>Selenium 50 Mcg</td>
</tr>
</tbody>
</table>

* Suggested values; within recommended ranges
** Dietary Goals

* Fiber = 1 gram/100 kcal
Items averaged:

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight: 2199 Grams (77.6 oz.)</td>
<td></td>
<td></td>
<td>Water weight: 1457 G</td>
<td></td>
</tr>
<tr>
<td>Calories</td>
<td>3213</td>
<td>146%</td>
<td>Vitamin B6</td>
<td>2.41</td>
</tr>
<tr>
<td>Protein</td>
<td>99.4 G</td>
<td>186%</td>
<td>Vitamin B12</td>
<td>3.99</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>547 G</td>
<td>172%</td>
<td>Folacin</td>
<td>264</td>
</tr>
<tr>
<td>Dietary Fiber</td>
<td>26.6 G</td>
<td>121%</td>
<td>Pantothenic</td>
<td>4.71</td>
</tr>
<tr>
<td>Fat-Total</td>
<td>74.8 G</td>
<td>102%</td>
<td>Vitamin C</td>
<td>493</td>
</tr>
<tr>
<td>Fat-Saturated</td>
<td>28.6 G</td>
<td>117%</td>
<td>Vitamin E</td>
<td>10.4</td>
</tr>
<tr>
<td>Fat-Mono</td>
<td>23.7 G</td>
<td>97%</td>
<td>Calcium</td>
<td>952</td>
</tr>
<tr>
<td>Fat-Poly</td>
<td>15.6 G</td>
<td>64%</td>
<td>Copper</td>
<td>1.68</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>274</td>
<td>91%</td>
<td>Iron</td>
<td>22.3</td>
</tr>
<tr>
<td>Vit A-Carotene</td>
<td>879</td>
<td></td>
<td>Magnesium</td>
<td>334</td>
</tr>
<tr>
<td>Vit A-Preformed</td>
<td>524</td>
<td></td>
<td>Phosphorus</td>
<td>1360</td>
</tr>
<tr>
<td>Vit A-Total</td>
<td>1403</td>
<td>175%</td>
<td>Potassium</td>
<td>2989</td>
</tr>
<tr>
<td>Thiamin-B1</td>
<td>2.44</td>
<td>278%</td>
<td>Selenium</td>
<td>167</td>
</tr>
<tr>
<td>Riboflavin-B2</td>
<td>2.2</td>
<td>200%</td>
<td>Sodium</td>
<td>4139</td>
</tr>
<tr>
<td>Niacin-B3</td>
<td>27.1</td>
<td>171%</td>
<td>Zinc</td>
<td>14.8</td>
</tr>
</tbody>
</table>

* Suggested values; within recommended ranges
** Dietary Goals    # Fiber = 1 gram/100 kcal

Calories from protein: 12% Poly/Sat = 0.5:1
Calories from carbohydrates: 67% Sod/Pot = 1.4:1
Calories from fats: 21% Ca/Phos = 0.7:1

CSI = 42.6
"No Bones About It!"
Nutrition Analysis Information

How to read your analysis:

The first page indicates the recommended amounts of nutrients for you based on your weight, height, age and a "moderate" activity level. Caloric intake is highly variable because each individual has a different body metabolism and actual activity level may vary from "moderate". Therefore, the recommended caloric intake should just be a rough estimate for you. Focus more on if your are getting adequate amounts of the "highlighted" nutrients - carbohydrates, protein, fats, calcium and iron, from a variety of food sources and that you are practicing good eating habits. These are key for developing lifelong healthy eating practices. Many other nutrients are listed as well for your information.

The second page indicates your average intake based on the 3 day food record you gave to me. It indicates beside each nutrient the actual amount you took in then the next column indicates what percentage of your recommended intake you got. At the bottom of the printout is indicated the percent of your diet that protein, carbohydrates and fats contribute. A recommended balance is:
- 15% of your total daily caloric intake from protein
- 60-70% from carbohydrate, and
- 20-30% from fats.

Your balance may be good, but you may not be getting enough total amounts of either carbohydrates or proteins, and you maybe getting too much fat. On the other hand, your balance may not be good but you might be getting most of your nutrients. Some slight modifications can usually improve your balance as well as make sure you get enough of the key nutrients. This is how I have based my comments written on the bottom of the print out for you.

A little about each of the key nutrients:

Calories: As I mentioned this is highly variable for each girl based on body size, activity level and metabolism. Getting enough calories is very important to promote normal growth and development. Many calories are needed during adolescence because you are growing. Depriving yourself of food can lead to the development of poor eating habits and often weight problems later in life. No one should be eating less than 1500 calories.

Carbohydrates: Carbohydrates are your immediate and best source of energy. They are the "GO!" food. Carbohydrates are also "brain" foods since they are the only energy source your brain can use. Carbohydrates are found in breads, cereals, grains, rice, potatoes, pasta, cakes, cookies, fruits and vegetables etc. You should be getting most of your daily calories from carbohydrates. If you do not get enough carbohydrates you will probably feel tired and your body will start using protein for energy instead of what protein is supposed to be used for (body growth and repair) (see below). Sources of complex carbohydrates eg. grains, cereal, bagels etc. tend to be higher in nutrients and
fiber, whereas sources of simple carbohydrates eg. cakes, cookies, donuts, chips etc. tend to be higher in fat, sugar and salt and low in fiber and nutrients. Eat lots of the complex ones and the simple ones in moderation.

**Protein:** Protein is needed for the growth and repair of your body tissues. It helps make up your bones and muscles for example, helps you grow, and fixes your tissues when they are damaged. With such an important role it is clear to see why we need to get adequate amounts. Protein sources come from animal or plant foods eg. meat, fish, poultry, eggs, cheese, milk, yogurt, beans, lentils, tofu etc. You need to get 2-3 servings of this food group daily. If fat intake is a concern for you (see your printout) try to choose white meat, fish and low or non fat dairy products for example.

**Fat:** Fat is an essential part of the diet. It is used for energy and it makes up important parts of your tissue such as nervous system tissue. Fat keeps us warm and gives us shape and protection for our body. Not enough fat, or too much fat can lead to health risks. It is recommended to keep daily fat intake at least below 30% of our total daily caloric intake. There are 3 kinds of fat, saturated, monounsaturated and polyunsaturated. It is recommended that we get 10% of total fat from each kind (your printout indicates how much of each you are eating). Saturated fats are already hidden in foods eg. animal fats (meat), butter, whole milk and cream products, baked goods etc. so we don't need to add them to other foods. Mono and unsaturated fats are found in oils so read food labels to see what kind of fats have been used in margarines, salad dressings, crackers, baked goods, fried foods etc.

Review your printout carefully and see the attached Canada Food Guide which will help you make wise choices in your eating. It indicates how many servings of each of the food groups you should be eating in a day, illustrates some good food choices, and what a serving size is. I also have a vegetarian food guide if anyone is interested, just let me know. Eating vegetarian can be a healthy, low fat, high carbohydrate way to eat with many benefits, however, to eat vegetarian properly (to get all your nutrients) is difficult unless you have a great deal of knowledge in the area and/or have spoken to a dietitian about setting up a plan. Eating vegetarian (vegan) during adolescence, when you are growing, can be a concern because it is difficult to get enough calories, protein and essential nutrients like vitamin B12, calcium and iron which are very important for females. **Calcium** is a very important nutrient for bone growth and development, and **iron** makes up a component of blood which carries oxygen to all your cells. These nutrients are not as available or absorbed as well from plant food sources. Eating a "lacto ovo" vegetarian diet, where you eat eggs and dairy products, or eating "semi vegetarian", where you include some meat products as well, helps make up for the concerns of eating a strict "vegan" diet.

There is so much information about healthy eating. I hope this has given you a few key and helpful tips. If you have any further questions please do not hesitate to call me at 984-7571. You will be doing another 3 day record in June/July.
Enjoy a variety of foods from each group every day.

Choose lower-fat foods more often.

**Grain Products**
Choose whole grain and enriched products more often.

**Vegetables & Fruit**
Choose dark green and orange vegetables and orange fruit more often.

**Milk Products**
Choose lower-fat milk products more often.

**Meat & Alternatives**
Choose leaner meats, poultry and fish, as well as dried peas, beans and lentils more often.
Different People Need Different Amounts of Food

The amount of food you need every day from the 4 food groups and other foods depends on your age, body size, activity level, whether you are male or female and if you are pregnant or breast-feeding. That's why the Food Guide gives a lower and higher number of servings for each food group. For example, young children can choose the lower number of servings, while male teenagers can go to the higher number. Most other people can choose servings somewhere in between.

### Grain Products

<table>
<thead>
<tr>
<th>1 Serving</th>
<th>2 Servings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Slice</td>
<td>1 Bagel, Pita or Bun</td>
</tr>
<tr>
<td>Cold Cereal</td>
<td>3/4 cup</td>
</tr>
<tr>
<td>Hot Cereal 175 mL</td>
<td></td>
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</tbody>
</table>

### Vegetables & Fruit

<table>
<thead>
<tr>
<th>1 Serving</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1 Medium Size Vegetable or Fruit</td>
<td></td>
</tr>
</tbody>
</table>

### Milk Products

<table>
<thead>
<tr>
<th>1 Serving</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>250 mL 1 cup</td>
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</tbody>
</table>

### Meat & Alternatives

<table>
<thead>
<tr>
<th>1 Serving</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1/3–2/3 Can 50–100 g</td>
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</tbody>
</table>

### Other Foods

Taste and enjoyment can also come from other foods and beverages that are not part of the 4 food groups. Some of these foods are higher in fat or Calories, so use these foods in moderation.

Enjoy eating well, being active and feeling good about yourself. That's VITALITY.
"No Bones About It!"
Study Individual Participant Results Summary

Name: __________________________

Below is a summary of your measurements and how they compare and have changed over the 18 month study period. A summary of the study findings and results will be mailed to you along with your nutritional analysis in a few months once the detailed analysis has been completed. As many of the measurements taken were size oriented you will notice that the numbers may have increased over the 18 months because you probably grew. A brief interpretation, comments and suggestions are included with each set of measurements below.

Bone Mineral Measures:

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<tr>
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<tbody>
<tr>
<td>total body bmc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total body bmd</td>
<td>g/cm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>spine bmc</td>
<td>g/cm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>spine bmd</td>
<td>g/cm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>femoral neck bmc</td>
<td>g/cm²</td>
<td></td>
<td></td>
</tr>
<tr>
<td>femoral neck bmd</td>
<td>g/cm²</td>
<td></td>
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</tbody>
</table>

bmc = bone mineral content (how much bone you have)

bmd = bone mineral content divided by bone area (density)

BMC and BMD were the most important measures because the whole purpose of the study was to increase them now while you are growing so as to prevent osteoporosis when you are older. If you grew your bmc should increase but not necessarily bmd. If you exercised and/or took calcium we think both bmc and bmd should increase above what you get from normal growth. The changes in the numbers may appear small but even small increases can have a major impact on bone strength. While you are growing is the best time to increase your bone mineral. Once you are an adult and stop growing the potential to increase bone is basically gone... so good nutrition and weight bearing exercise like weight training is so important right now! Take advantage of this time - read your healthy bone tips. Unless if otherwise stated your bone mineral is within the normal range. As this is one of the first long term studies on adolescent bone, there is not much to compare to so we have also adapted adult bone mineral norms for comparison.
Body Size and Composition Measures:

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<tr>
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<tr>
<td>height (cm)</td>
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<td></td>
</tr>
<tr>
<td>weight (kg)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>sum of skinfolds (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% body fat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lean mass (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>waist (cm)</td>
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<td></td>
<td></td>
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<tr>
<td>hips (cm)</td>
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<td></td>
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<tr>
<td>thigh (cm)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>upper arm (cm)</td>
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</table>

Body composition consists of muscle, bone and fat basically plus all your organs and water. Typically in our society the focus is on body fat and views it negatively, however, fat serves very important functions for our body so we need it. Too much excess fat can pose a health risk so during your teenage years is the best time to build healthy exercise and eating habits that you can carry on throughout your life to maintain a healthy body composition. During puberty you will increase in height, weight, fat tissue (% sum of skinfolds) which is normal. Girth measurements (eg. upper arm, thigh) will also increase in size. These measurements may also get bigger through weight training or an increase in fat tissue. Sometimes girths get smaller from weight training because excess fat is used for energy and muscles become toned and streamlined. % body fat, as measured on the bone scan machine, are very accurate but typically result in higher values than other less direct methods so do not let your score worry you. It is recommended to keep body fat below 34% for optimal health. Regular exercise and healthy eating patterns are the best way to maintain a healthy weight. Refer back to the nutrition handout (Canada Food Guide and tips) and analysis I gave you last spring. Choose low fat, high nutrient foods from all four food groups, eat often but small meals vs. one large meal, eat breakfast, enjoy a few treats, have lots of variety and enjoy healthy eating. I will also send you more information with your next dietary analysis result.

Comments:_____________

_____________

352
Your strength will increase as you grow just because of your bigger size but weight-training will increase strength further. Increased strength can help increase performance in other activities and sports you do, help you enjoy more physical challenges and pursuits, decrease fatigue, increase feelings of accomplishment and self esteem, help control body weight and fat, increase toned appearance of your body, and can be a fun activity. For those of you who did weight train try to incorporate it into your regular exercise routine and for those of you in the control group there is a weight training information package in your bag so you can get started and enjoy the benefits of weight-training too. There is a strong relationship between muscle strength and strong bones too!

Comments: ____________________________________________

I hope you have found these results interesting and informative. If you have any questions about them please feel free to call me. I know the testing took awhile but you are lucky to have them done because you now know where you stand in terms of your bone health and muscle and fat levels so you have the opportunity to do something positive to increase your health for the rest of your life. Thank you again for your contribution and many other young women will be thanking you too when they read about the conclusions of the study.
Glossary

amenorrhea (secondary) - absence or abnormal stoppage of menses, e.g. possibly through excessive exercise and/or severe weight loss, once it has been established at puberty; although various definitions exist having fewer than periods a year can be described as amenorrhea

anorexia nervosa - a mental disorder occurring mostly in females, with a usual onset in adolescence, and characterized by refusal to maintain a normal body weight, intense fear of becoming obese that persists even with weight loss, disturbance of body image resulting in feeling of being fat even when extremely emaciated, and amenorrhea (in females)

appositional bone growth - the deposition of new bone in successive layers upon the bone surface resulting in an increase in the width of bone

body mass index (BMI) - a ratio calculated by dividing body weight (kg) by height (m$^2$) and used to indicate health-risk zone in the average population

bone densitometry - techniques used to measure bone mineral content and density through measurement of absorption and attenuation of radiation beams scanning the bone

bone mass - the total amount of bone an individual has at any one time; a term used generally, as bone mass cannot be measured, to refer to bone mineral content or density, which can be measured

bone mineral apparent density (BMAD) - a volumetric density (g/cm$^3$) using a volume estimated from the projected area obtained from an areal bone mineral measurement

bone mineral content - the mass of mineral in a specified area of bone measured in grams

bone mineral density - the mass of mineral in a projected area of bone divided by its volume and expressed in g/cm$^2$ as measured by DXA

bone modeling - a process occurring during growth where bone increases in size (width and length) and changes shape by the persistence of bone formation or resorption during the growth period; it is the principle mode of bone turnover in the growing skeleton
bone remodeling - a mode of bone turnover predominately in the adult skeleton which is continually resorbing old bone and laying new bone down on the bone surfaces; the consequences of remodeling, i.e., positive, negative or neutral bone balance, depend on environmental, nutritional, and hormonal factors influencing the rate of remodeling

calcitonin - an anti-resorptive hormone secreted from the thyroid gland in response to hypercalcemia (high serum-calcium levels), it lowers serum calcium by moving calcium into bone tissue, it inhibits bone resorption and acts as an antagonist to parathyroid hormone in the feedback system of regulating serum calcium levels

calcium - the most abundant mineral in the body, most of which is stored in the bones; together with phosphorus it forms the hard material of bones and teeth, it is an essential dietary element; a constant blood calcium level is required for the normal heartbeat and functioning of nerves and muscles

cortical bone - is the compact bone of the shaft of long bones which surrounds the medullary canal; bone cells are tightly packed around canals which bring blood to the bone cells, cortical bone provides compression-resistance strength

dual-energy X-ray absorptiometry - a bone densitometry technique to measure bone mineral content and bone mineral density; it involves two X-ray beams of different energies which differentiate between bone tissue and soft tissue (bone free lean and fat tissue)

estrogen - a family of hormones secreted by the ovaries necessary for female secondary sex characteristics and reproductive functioning, and it also increases the absorption of dietary calcium from the intestine and blunts the effects of parathyroid hormone (which promotes release of calcium from bone)

femoral neck - the proximal region of the femur bone at the junction of the shaft and head of the bone (greater trochanter); a common site for osteoporotic fracture

health education - any combination of learning experiences designed to facilitate voluntary actions and behaviours conducive to health

health promotion - any combination of educational and environmental supports for actions and conditions of living conducive to health

hydroxyapatite - an inorganic compound made mostly of calcium and phosphorus, found in the matrix of bone and teeth which gives rigidity to these structures
matrix - the hard substance of bone including organic collagen fibers and vertical and horizontal plates of bone, which form the basis from which a structure can develop; specifically in bone it is where the inorganic crystals of calcium and phosphorus (hydroxyapatite) are deposited

menarche - the event during puberty when a female establishes or begins menstrual function

oligomenorrhea - menstrual dysfunction, irregular cycles, markedly diminished menstrual flow

osteoblasts - bone cells which as they mature are responsible for the production of new bone

osteocytes - osteoblasts which has become embedded in the bone matrix and are responsible for breaking down the matrix during bone resorption in the processes of bone remodeling and modeling

osteopenia - reduced bone mass to below normal levels (1-2.5 standard deviations below normal), due to decreased bone matrix formation

osteoporosis - a progressive disease characterized by severe loss of bone mass, 2.5 standard deviations or greater below normal, increasing porosity and risk of fracture after minimal trauma

peak bone mass - the greatest mass of bone accumulated during growth

PRECEDE - predisposing, reinforcing, enabling constructs in educational development and environment

PROCEED - policy, regulatory, organizational constructs in educational and environmental development

quality of life - a phrase coining qualities, conditions, situations etc. which contribute to making ones life enjoyable, satisfying and rewarding

resorption - local reduction of bone volume due to removal of mineral and organic matrix from bone surfaces mediated by osteoclasts; the first phase in bone remodeling

trabecular - a type of bone which is characterized by thick vertical plates joined with thinner horizontal plates to form a matrix; found in bones of the axial skeleton and the ends of long bones (Taylor, 1988)