# STUDIES OF FALL RISK AND BONE MORPHOLOGY IN OLDER WOMEN WITH LOW BONE MASS

by

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## Abstract

**Introduction**

Osteoporotic fractures are a major health care problem. Fracture risk can be largely divided into two domains: fall risk and bone health, and both can be influenced by exercise.

**Purpose**

1) To examine the role of different types of exercise on both fall risk and bone health in older women with low bone mass. 2) To explore fall risk factors that may be unique to women with low bone mass.

**Methods**

*Subjects:* Women aged 65 to 75 years with osteoporosis for Parts I and II. Women aged 75 to 85 years with low bone mass (i.e. osteoporosis or osteopenia) for Parts III, IV, and V.

*Study Design:* Parts I and II are cross-sectional studies. Parts III, IV, and V involved a 25-week randomized controlled trial of resistance training, agility training, and stretching (sham exercise).

**Results**

*Parts I & II:* Back pain was negatively associated with both postural stability ($r^2 = 0.09$, $p = 0.04$) and functional mobility ($r^2 = 0.12$, $p = 0.001$). Compared to their counterparts without osteoporosis, older women with osteoporosis had 11 to 18% greater fall risk by composite balance score and quadriceps strength (both $p < 0.03$). *Part III to V:* Both high-intensity resistance training and agility training significantly reduced fall risk compared to a general stretching program (both $p < 0.01$). The resistance training program reduced fall risk by 57% and the agility training program reduced fall risk by 48% without any serious adverse effects. Both exercise programs also significantly increased cortical bone density (by pQCT) in the appendicular skeleton. Fear of falling was also reduced after 13 weeks of participating in both exercise programs.

**Conclusions**

The cross-sectional studies suggest that back pain may warrant scrutiny as a fall risk factor in older women with osteoporosis and that older women with osteoporosis may be at greater risk of falls than is often recognised. The RCT indicates that in women aged 75 to 85 years with low bone mass both high-intensity resistance training and agility training reduce fall risk compared to general stretching. Also, both types of training have the potential to increase cortical bone density in a site-specific manner despite the population being elderly. Change in balance confidence may not correlate closely with changes in physiological measures of fall risk. Further studies in high-risk populations should be powered for falls as the primary outcome.

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## Glossary of Terms and Abbreviations Used In This Thesis

DXA — Dual energy X-ray absorptiometry.

pQCT — Peripheral quantitative computed tomography.

BMC — Bone mineral content (grams).

BMD — Bone mineral density. Expressed in $mg/cm^3$ when measured by pQCT (i.e., volumetric BMD). Expressed in $g/cm^2$ when measured by DXA (i.e., areal BMD).

Bone Health — Refers to all factors that contribute to the mechanical competence of bone (e.g., bone material, structure, and turnover rate).

CortD — Cortical density in $mg/cm^3$.

CSMI — Cross-sectional moment of inertia.

CSA — Cross-sectional area ($mm^2$).

CV — Coefficient of variation. It accounts for the relationship between the mean and standard deviation.

SOT — Sensory organization test provided by the Equitest computerized dynamic posturography platform (Neurocom International, Clackamas, Oregron).

OVX — Ovariectomy or ovariectomized.

## Preface: Publications Arising From This Thesis

Sections of this thesis have been published as multi-authored papers in refereed journals, which are indicated with an asterisk (*) beside the publications below. Details of authors' contributions are provided, where relevant.

We agree with the stated contributions of the thesis author, as indicated below.

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Dr. Karim Khan (Thesis Supervisor)

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Dr. Heather McKay (Thesis Co-Supervisor)


**Published Papers**

**\*Liu-Ambrose T,** Khan KM, Eng JJ, Lord SR, McKay HA. Balance confidence increases with resistance or agility training: Increase is not correlated with objective changes in fall risk and physical abilities. Gerontology, 2004 (In Press).
*Authors' contributions:* Teresa Liu-Ambrose was responsible for the original ideas behind the paper, analysis and presentation of findings, and writing and editing of the original paper. Karim Khan was the key editor on this paper. Janice Eng, Stephen Lord, and Heather McKay stimulated discussion of results and provided editorial assistance.

**\*Liu-Ambrose T,** Khan KM, Eng JJ, Janssen PA, Lord SR, McKay HA. Both resistance and agility training reduce fall risk in 75-85 year old women with low bone mass: A six-month randomized controlled trial. Journal of the American Geriatrics Society, 2004 (In Press).
*Authors' contributions:* Teresa Liu-Ambrose was responsible for the original ideas behind the paper, analysis and presentation of findings, and writing and editing of the original paper. Karim Khan and Stephen Lord were key editors on this paper. Janice Eng and Heather McKay stimulated discussion of results and provided editorial assistance. Patti Janssen provided ongoing statistical consultation throughout data analysis.

**\*Liu-Ambrose T,** Eng JJ, Khan KM, Carter ND, McKay HA. Older women with osteoporosis have increased postural sway and weaker quadriceps than counterparts with normal bone mass: Overlooked determinants of fracture risk? Journal of Gerontology 2003; 18:M862-M866.
*Authors' contributions:* Teresa Liu-Ambrose was responsible for the original ideas behind the paper, analysis and presentation of findings, and writing and editing of the original paper. Janice Eng and Karim Khan were key editors on this paper. Heather McKay stimulated discussion of results and provided editorial assistance. Nick Carter assisted with data collection and discussion of results.

**\*Liu-Ambrose T,** Eng JJ, Khan KM, Mallinson A, Carter ND, McKay HA. The influence of back pain on balance and functional mobility in 65- to 75-year-old women with osteoporosis. Osteoporosis International 2002; 13:868-873.
*Authors' contributions:* Teresa Liu-Ambrose was responsible for the original ideas behind the paper, analysis and presentation of findings, and writing and editing of the original paper. Janice Eng and Karim Khan were key editors on this paper. Heather McKay stimulated discussion of results and provided editorial assistance. Nick Carter and Art Mallinson assisted with data collection and stimulated discussion of results.

## Submitted Papers

**\*Liu-Ambrose T**, Khan KM, Eng JJ, McKay HA. Cortical bone density increases with both resistance and agility training: A six-month randomized controlled trial. Submitted to Journal of Gerontology, January 2004.

***Authors' contributions:*** Teresa Liu-Ambrose was responsible for the original ideas behind the paper, analysis and presentation of findings, and writing and editing of the original paper. Heather McKay and Karim Khan were key editors on this paper. Janice Eng stimulated discussion of results and provided editorial assistance.

## Abstracts

I presented those abstracts with an asterisk (\*) orally or as a poster at the conference indicated.

**Liu-Ambrose T**, Khan KM, Eng JJ, Lord SR, McKay HA. Agility or resistance training significantly reduces fall risk in 75 to 85 year-old women with low bone mass: A randomized controlled trial. Medicine and Science in Sports and Exercise 2003; 35(5S):S196.

Khan KM, **Liu-Ambrose T**, Eng JJ, Lord SR, McKay HA. Effect of resistance or agility training on bone parameters in older women with low bone mass. Medicine and Science in Sports and Exercise 2003; 35(5S):S71.

Whitney C, **Liu-Ambrose T**, Khan KM, Eng JJ, Lord SR, McKay HA. Agility, posture, or resistance training all improve dynamic balance in postmenopausal women. Medicine and Science in Sports and Exercise 2003; 35(5S):S167.

Clarke LH, **Liu-Ambrose T**, McKay HA, Khan KM, Zyla J. Older osteoporotic women's perception of health, quality of life and well-being. 14th International Congress on Women's Health Issues, Victoria, BC, 2003.

**\*Liu-Ambrose T**, Khan KM, Eng JJ, Lord SR, McKay HA. The differences between agility training and resistance training in reducing fall risk in older women: A six-month RCT. International Symposium on Posture and Gait Research, Oral Presentation, March 2003, Sydney, Australia.

**Liu-Ambrose T**, Eng JJ, Khan KM, Carter ND, Mallinson A, McKay HA. Balance and functional mobility differences between women with osteoporosis and women without osteoporosis. Medicine and Science in Sports and Medicine 2002; 34(5):S271.

\*Khan KM, Carter ND, Waterman C, Donaldson M, **Liu-Ambrose T**, Mallinson A, Kruse K, Petit M, Janssen P, Riddell L, Prior JC, Heinonen A, McKay HA. "Osteofit", a community-based exercise program reduces fall risk by improving dynamic balance in 65-75 yr old women who have osteoporosis. American Society of Bone and Mineral Joint Research Annual Meeting, Poster Presentation, October 2001, Phoenix, Arizona.

## Acknowledgements

## Chapter One:  Introduction

Osteoporosis is a skeletal disorder characterized by compromised bone strength predisposing a person to an increased risk of fracture (1).  The absolute numbers and age-specific incidence rates of osteoporotic fractures have increased all over the world during recent decades, with a three-fold increase predicted by 2050 (2).  There are over 24,000 hip fractures in Canada each year (3) that result in an annual health care cost of 650 million dollars (4).  Without a successful population level intervention, the present public health problem is likely to worsen (5).  Consequently, there is a need for an efficient and cost-effective prevention of osteoporotic fractures that would be feasible at the population level and that would not require special resources or expertise from the health care system.

There are many well-recognized risk factors for osteoporotic fractures and they are often categorized into amendable or non-amendable factors.  Non-amendable factors include increasing age, female sex, and Caucasian race.  Amendable risk factors include impaired postural stability, decreased muscle strength, and low bone mass.  Amendable risk factors for fracture can be largely divided into two domains:  fall risk and bone health.  More distant risk factors for fracture, such as fall severity and body habitus, operate via these two domains.

Bone strength, which encompasses both material (e.g., density) and structural (e.g., cross-sectional area) properties of bone, contributes to fracture risk.  For example, for every standard deviation decrease in femoral neck bone areal bone mineral density (BMD) the age-adjusted risk of hip fracture increases 2.6 times (6).  However, one cannot ignore the fact that approximately 90% of all hip fractures in older people occur secondary to a fall (7).  Thus, to prevent fractures in older people, both bone strength and fall prevention should be encouraged (8).  This contention is substantiated by a large prospective study of fracture incidence in both men and women which found that next to femoral neck areal BMD, two established fall risk factors, quadriceps strength and postural sway, were the best predictors of fracture (9).

There is strong evidence that exercise can positively influence both fall risk (10,11) and bone health (12,13).  Exercise is attractive as a mean of fracture prevention as it can be relatively inexpensive

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and widely accessible. It also has ancillary health benefits . However, "telling an older person that 'exercise' could help prevent falls is not much better than telling them that 'antibiotics' could cure an infection: although true, the advice would be much more useful if it were more specific (14)". As the specifics of exercise prescription for optimum fracture prevention are not established, further work is required to delineate the parameters, such as frequency, intensity, type, and duration of such exercise programs for older people. This is especially true for those who are at particular risk of sustaining fractures from falls, such as older women with low bone mass. A recent systematic review of randomized trials of exercise on bone mass in women concluded that, "Randomized trials comparing the effects of different exercise programs on both bone- and fall-related outcomes are needed." (15).

Therefore, the primary purpose of this five-part thesis is to examine the role of different types of exercise on both fall risk and bone health in older postmenopausal women with low bone mass. The secondary purpose is to explore fall risk factors that may be unique to those with low bone mass (i.e., osteopenia or osteoporosis). In Part I (Chapter Four), I examine the association between back pain, a prevalent condition in those with osteoporosis, and postural stability and functional mobility (i.e., fall risk factors) among 65 to 75 year old women with osteoporosis. Part II (Chapter Five) compares three physiological fall risk factors (quadriceps strength, postural stability, and functional mobility) between women with osteoporosis and age-matched counterparts without osteoporosis. Parts III and IV (Chapters Six & Seven) describe a randomized controlled trial of two different group-based exercise programs (high-intensity resistance training and agility training) on standardized fall risk scores (Part III) and bone health (Part IV) in community-dwelling older women with low bone mass. Part V (Chapter Eight) investigates the relationship between change in balance confidence and changes in physiological function in community-dwelling older women with low bone mass after participating in group-based exercise programs.

## Chapter Two:  Literature Review and Background

## 2.1 Falls in Older People

In this section, I firstly report the epidemiology of falls in community-dwelling older adults, identify fall risk factors, injurious fall risk factors, and discuss age-related physiological changes associated with increased fall risk.  Next, I discuss the validity and reliability of the Physiological Profile Assessment (PPA) ©(16) (Prince of Wales Medical Research Institute, Randwick, Sydney, NSW, Australia) as a method of fall risk evaluation.  The section concludes by detailing published exercise interventions that aimed to reduce either fall risk factors or falls in community-dwelling older adults.

### 2.1.1 Epidemiology of Falls in Community-Dwelling Older Adults

A fall is defined as "unintentionally coming to the ground or some lower level and other than as a consequence of sustaining a violent blow, loss of consciousness, sudden onset of paralysis as in stroke or an epileptic seizure" (17).  Approximately 30% of community-dwelling adults over 65 years of age fall at least once per year (18).  Older women have a higher incidence of falls compared with older men (19).  The proportion of women who fall increase from about 30% in the 65 to 69 year age group to over 50% in those over the age of 85 years.  The proportion of men who fall increase from 13% in the 65 to 69 year age group to approximately 30% in those aged 80 years and over (19).

Fall-related injuries are the leading cause of mortality due to unintentional injuries among those 65 and older.  Falls caused over 2,100 deaths (1%) among people aged over 65 in Canada in 1995 (20).  Depending on the population under study, between 22 and 60% of older people suffer injuries from falls, 10 to 15% suffer serious injuries, 2 to 6% suffer fractures (21).  In terms of morbidity and mortality, the most serious of these fall-related injuries is fracture of the hip.  In many instances, hip fractures result in death and of those who survive, many never regain complete mobility (21).  Although falls are often referred to as accidents, it has been shown statistically that they are not random events (22).  Thus, causal processes are likely involved in the events of falls and a number of physiological and medical fall risk factors have been identified.

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## 2.1.2 Fall Risk Factors

Numerous fall risk factors have been identified in the literature and they are often divided into intrinsic factors (i.e., increased personal liability to fall) and extrinsic factors (i.e., increased opportunity to fall). For example, impaired postural stability is an intrinsic risk factor and cracked pavement is an extrinsic risk factor. Extrinsic risk factors are beyond the scope of this literature review as the focus of this thesis is on intrinsic fall risk factors. Table 1 is taken from Grisso, Capezutti, and Schwartz (23) and it rates the association of each intrinsic risk factor with falls based on published evidence. Fall prevention programs must focus on amendable factors to be effective.

Table 1. Fall risk factors (23).

| Intrinsic Risk Factor | Evidence for Association* |
|---|:---:|
| Demographic Characteristics | |
| • Older Age | ++ |
| • Gender, Women | + |
| • Race, White | +/- |
| Functional Level | |
| • ADL/IADL | ++ |
| • Cane/Walker Use | ++ |
| • History of Falls | ++ |
| Gait, Balance, Strength | |
| • Gait Speed | ++ |
| • Postural Sway | ++ |
| • Lower Extremity Strength | ++ |
| • Upper Extremity Strength | ++ |
| • Impaired Reflexes | ++ |
| Sensory | |
| • Vision | ++ |
| • Lower Extremity Sensory Perception | ++ |
| Chronic Illnesses | |
| • Heart Disease | +/- |
| • Parkinson's Disease | ++ |
| • Other Neuromuscular Disease | ++ |
| • Stroke | ++ |
| • Urinary Incontinence | ++ |
| • Arthritis | + |
| • Acute Illness | + |
| Medications, Alcohol | |
| • Number of Mediations Used | ++ |
| • Hypnotics | ++ |
| • Sedatives | ++ |

| Intrinsic Risk Factor | Evidence for Association* |
|---|---|
| • Antipsychotic Medications | ++ |
| • Antiparkinsonian Medications | ++ |
| • Cardiac | +/- |
| • Diuretics | +/- |
| • Antihypertensives | +/- |
| • Alcohol | +/- |
| Mental Status | |
| • Cognitive Impairment | ++ |
| • Depression | ++ |

*++ is strong; = is moderate; +/- is inconsistent.

### 2.1.3 Risk Factors for Injurious Falls

Although falling is the strongest single risk factor for a fracture in an older person, only 1 to 2% of falls result in hip fractures and 2 to 6% result in fracture other than the hip in community-dwelling older adults. In addition, even older women with very low areal BMD of the proximal femur have only about a 2% annual risk of hip fracture. Thus, the question, "What separates those who fall without consequence from those who fall with consequence?" needs to be addressed to identify those in particular need of fall prevention. A number of studies have identified risk factors associated with injurious falls. Cognitive impairment, the presence of at least two chronic medical conditions, postural instability and gait impairment, and low body mass index (BMI) have been identified as risk factors for sustaining serious injury during a fall in older community-dwelling individuals (24). Other risk factors of injurious falls are: older age, Caucasian race, decreased areal BMD, reduced visual acuity (25) and impaired neuromuscular function (such as increased reaction time and decreased muscle strength) (26).

### 2.1.4 Age-Related Physiological Changes Associated with Increased Fall Risk in Older People

Postural stability can be defined as the ability to maintain centre of mass within limits of stability. Stability limits are boundaries in which the body can maintain its position without changing the base of support. The maintenance of postural stability is a complex activity requiring input from many sensory systems, integration of this information at many levels of the nervous system, and a musculoskeletal system to implement the commands from the central nervous system (CNS) (27). The visual, vestibular,

and somatosensory systems are the primary sensory systems, but hearing and autonomic systems also play a role (27). The incidence of falls increases with age and in part, is related to age-related changes in the systems that contribute to postural stability. It is noted, however, that much of the decline in postural stability associated with aging is not the result of aging per se but rather the result of physical inactivity.

Figure 1 is a conceptual model of the postural control system described by Maki and McIlroy (28). This conceptual model is based on three components: the sensory input systems, the central processing control systems, and the effector systems. Sensory input from the visual, vestibular, and proprioceptive systems provides information on the orientation of the body relative to the environment and information on the environment itself. The central processing control systems function to assess and integrate the sensory input and select an appropriate sensorimotor response for the effector system, while the effector system executes some action that is timely and effective in responding to the sensory input. Normal aging is associated with changes in all three components and I discuss each in this section.
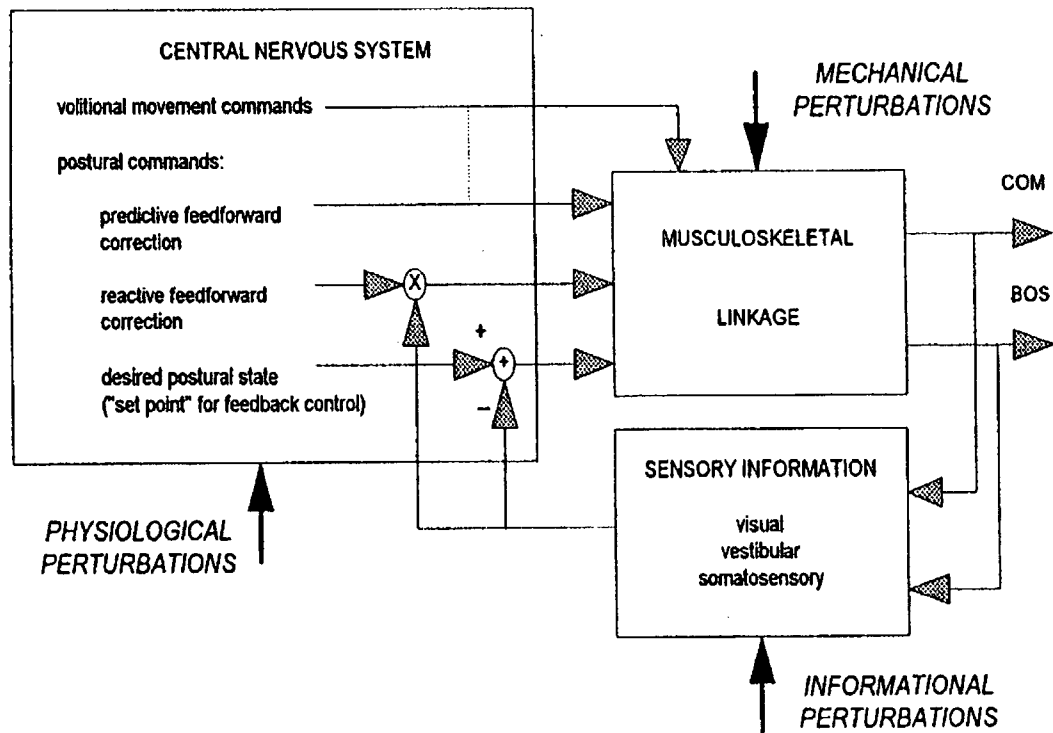
Figure 1. A conceptual model of the posture control system. In feedback control, sensory information is used to continuously update the corrective changes to the center of mass (COM) or base of support (BOS). In feedforward control, preprogrammed stabilizing reactions are released, either predictively (anticipatory postural adjustments) or in reaction to sensory information pertaining to the state of instability (triggered postural reactions). Mechanical perturbations involve change in the forces acting on the body (due to movement of the body and/or interaction with the environment). Informational perturbations pertain to transient change in the nature of the orientational information available from the environment. Physiologic perturbations refer to transient internal events that disrupt the operation of the neural control system (28).

2.1.4.1 Age-Related Changes in the Sensory System

Vision plays an important role in postural stability maintenance by providing the nervous system with continually updated information regarding the position and movements of body segments in relation to each other and the environment (29). Changes in the visual system associated with advancing age include reduced acuity, contrast sensitivity, depth perception, dark adaptation, and restriction of the visual field (28,30).

The contribution of vision to postural stability has been well demonstrated. For example, postural sway synchronizes with small (4mm), low frequency (0.25 Hz) sinusoidal movements of the wall in front of the subjects, even though most subjects were not aware of these movements (31). Also, logarithmic decreases in visual acuity caused a linear increase in postural sway (32). This increase in postural sway was twice as prominent in the sagittal plane (anterior-posterior) as in the coronal plane (mediolateral).

In a recent prospective study, impaired vision was an important and independent risk factor for falls (33). Adequate depth perception and distant edge contrast sensitivity were particularly important for maintaining postural stability and detecting and avoiding hazards in the environment. Vision takes on a much greater role when proprioception is diminished or rendered unreliable (34,35).

The vestibular system provides input as to the head position in relation to gravity and it also senses how fast, and in which direction, the head is accelerating (36). Specifically, the vestibular system has six semicircular canals that sense angular (rotational) head movements and two utricles and saccules to sense linear head movements and the acceleration of gravity (27). The major contribution of the vestibular apparatus to postural stability is in maintaining the reflex associated with keeping the head and neck in a vertical position, and in corrective movements elicited through vestibulospinal and vestibuloreticulospinal pathways (30).

This system shows a progressive loss of labyrinthine hair cells, vestibular ganglion cells, and nerve fibers, and there are age-related changes in the vestibulo-ocular reflex that are consistent with these peripheral anatomic changes (28). The relationship of vestibular impairment secondary to age-related

changes to postural instability has not been studied extensively as it is less amendable to experimental manipulation than the other two senses (30).

A large cross-sectional study involving 550 women, between the ages of 20 and 99 years old, demonstrated that vestibular function significantly contributed to a person's ability to stand on a foam with eyes closed (37). Using the sensory organization test (SOT) of the EquiTest (NeuroCom International, Clackamas, Oregon) computerized dynamic postural test system to collect normative data on postural balance in asymptomatic, ambulatory, community-dwelling adults, age-related changes in vestibular function were associated with significant age-associated decline in the composite balance score (38).

Specific exercises appear to be effective for treating individuals with vestibular deficits. Vestibular rehabilitation is an exercise-based approach designed to maximize central nervous system compensation for vestibular pathology (39). In a double-blinded, placebo controlled randomized controlled trial, vestibular rehabilitation significantly improved gait velocity and stability after 6 weeks (40).

Peripheral sensation includes vibration sense, tactile sensitivity, kinaesthetic awareness, and proprioception (21,30). There is an age-related reduction in peripheral sensation (41-44). Specifically, vibration sense to all vibration frequencies greater than 50 Hz declines with age (21). Also, vibration sense is poorer in the lower limb compared with the upper limb at all ages and it shows a greater age-related decline (21).

Similarly, tactile sensitivity, as assessed by aesthesiometers or by two-point discrimination, decreases significantly with age and is reduced in the lower limb compared with the upper limb (45,46). Kinaesthetic awareness, or joint position sense, has also been repeatedly shown to decline with age (41,42). Cross-sectional data suggest that regular physical activity may attenuate this age-related decline in joint position sense (47). Furthermore, in a three-week prospective study involving eight young adults, balance training improved joint position sense (48).

Proprioception refers to the unconscious awareness of joint position sense (versus kinaesthetic awareness which is conscious awareness). Empirically, the significance of ankle proprioception for

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balance retention in the older people was shown (34) in a study that compared the postural sway of 12 older adults (61 to 78 years old) with that of 12 young adults (19 to 38 years). Older adults had large increases in postural sway when ankle proprioception was eliminated. These increases were significantly greater than those of the young adults.

A number of cross-sectional studies have highlighted the association between impaired peripheral sensation and postural instability (49,50). One study demonstrated older adults (70 years old or greater) with impaired joint position sense (threshold to detection of motion) at the knee joint had significantly increased centre of pressure (COP) variance compared with age-matched individuals with better joint position sense (49). Another study demonstrated that poor tactile sensation, poor joint position sense at the knee joint (matching joint position), and reduced vibration sense were associated with increased postural sway, leading the investigators to conclude that peripheral sensation is the most important sensory system in the maintenance of static postural stability (50).

2.1.4.2 Age-Related Changes in Central Processing

Normal aging brings a number of changes to the CNS that could impact on postural stability, including loss of neurons, dendrite loss and reduced branching, impaired cerebral metabolism, reduced cerebral perfusion, and altered transmitter metabolism.(51). It is likely that these changes disrupt the mobilization of complex postural responses as well as reduce the ability to compensate for age-related impairments in sensory input (28). In addition, a general slowing of information processing (30), in conjunction with age-related decrease in nerve conduction velocity, would be expected to delay and further disrupt the generation of postural responses. The functional significance of such changes is indirectly substantiated by the observed relationship between impaired reaction time and falls (52).

Furthermore, the maintenance of postural stability in older adults may increase the demand on high-level CNS resources such as the attention system, to compensate for age-related sensory deficits. The ability to recover a stable posture following an external perturbation is attentionally demanding for older adults than for younger adults (53,54). For example, recovery from postural instability induced by rapid arm

swinging was unaffected by the concurrent performance of a secondary mental arithmetic task in young adults, but impaired in older adults (53). Thus, there may be an increased risk for loss of balance and falls for older adults if sufficient attentional resources are not allocated to the task of postural recovery (54).

2.1.4.3 Age-Related Changes in the Musculoskeletal (Effector) System

Lean muscle mass and strength decline with age (55,56). Decrease in strength with age is associated with decreases in muscle area, number of muscle fibers, and number of motor neurons (28). Specifically, an accelerated loss of total muscle area and a decrease in muscle fiber number begins at about 50 years of age (57). Losses in spinal motor neurons and motor units become apparent at about 60 years of age. A 15% loss in muscle strength per decade occurs between the ages of 50 and 70 years (58). Quadriceps strength of healthy 80-year old individuals has been is 30% lower than that of 70 year olds (59). This is a rather large deficit over the span of only a decade.

Decreased muscle strength is associated with postural instability (37,50,60). In a cross-sectional study involving in 50 community-dwelling older adults aged 65 years and older, dorsiflexor and subtalar evertor force accounted for 58% of the variance in the Berg Balance Scale, and ankle plantarflexor accounted for 13% of the variance in the Functional Reach Test (60).

It is clear from a number of randomized controlled trials that resistance training can substantially increase muscle strength among community-dwelling older adults (61-64). However, the effects of resistance training on the loss of spinal motor neurons, motor units, and muscle fiber numbers are not well-established (57).

### 2.1.5 Assessment of Fall Risk: Physiological Profile Assessment (PPA)

As more than 130 different fall risk factors have been identified in the literature (65), the task of determining fall risk on an individual basis can be daunting. Thus, a vital question in fall risk assessment is, "What are the most important fall risk factors that need to be evaluated to accurately predict one's risk of future falls?"

Lord and colleagues identified five key amendable physiological fall risk factors as being the most important for discriminating older fallers from older nonfallers (52,66,67). The five discriminatory items were: edge contrast sensitivity, joint position sense, dominant quadriceps strength, hand reaction time, and postural stability, or total sway path, when standing on foam rubber mat with eyes open. These five discriminatory items represent the physiological domains of vision, proprioception, strength, reaction time, and postural stability and are the key components of Lord's Physiological Profile Assessment (PPA) ©(16) (Prince of Wales Medical Research Institute, Randwick, Sydney, NSW, Australia). The PPA has been devised to complement the medical assessment and management of older people who are at risk of falling. The PPA provides a single fall risk score based on the performance of the five discriminatory items and this score has a 75% predictive accuracy for falls in older people (52,66). The single fall risk score is a standardized score (z-score) that compares an individual's performance and fall risk to persons aged 65 years. Fall risk scores below 0 indicate a low risk of falling, scores between 0 and 1 indicate a mild risk of falling, scores between 1 and 2 indicate a moderate risk of falling and scores above 2 indicate a high risk of falling.

Standardised weightings for each of the five items were derived from a discriminant function for predicting multiple falls from the Randwick Falls and Fractures Study (66). These weightings (canonical correlation coefficients) were -0.33 for edge contrast sensitivity, 0.20 for joint position sense, -0.16 for isometric quadriceps strength, 0.47 for hand reaction time, and 0.51 for postural sway on foam rubber mat with eyes open.

2.1.5.1 Advantages of the PPA

The advantages of using the PPA in both the clinical and the research setting as summarized by Lord and colleagues (16) are:

1. Simple to administer: Only minimal training is required for proficiency in test administration.

2. Short administration time: The short version of the PPA takes only 10 to 15 minutes. The comprehensive version takes 45 minutes. Quick administration time aids participation and avoids fatigue in frail older people.

3. Feasible for older people to undertake: The assessments need to be acceptable to older people, in that they need to be non-invasive and not require excessive effort or cause pain or discomfort.

4. Valid and reliable measurements: When combined in a multivariate discriminant analyses, these measurements have been found to predict those at risk of falling with 75 to 79% accuracy in both community and institutional settings (52,66,67). In a one-year prospective study involving 414 community-dwelling women aged 65 to 99 years, the PPA measurement correctly classified subjects into a multiple falls group or a non-multiple falls group with an accuracy of 75% (66). Reliability coefficients for the five key discriminatory items of the PPA are reported in Table 2.

Table 2. Reliability coefficients for the five key discriminatory items of the PPA (16).

| Assessment | ICC* | 95% CI |
|---|---|---|
| Edge contrast sensitivity | 0.81 | 0.70-0.88 |
| Joint position sense | 0.50 | 0.15-0.74 |
| Quadriceps strength | 0.97 | 0.93-0.98 |
| Hand reaction time | 0.69 | 0.45-0.84 |
| Postural sway on foam rubber mat with eyes open | 0.57 | 0.30-0.76 |

*ICC = Intraclass correlation coefficients.

5. Quantitative measurements. A fundamental criterion for each test item of the PPA is that they provide continuously scored measurement, that is, quantitative rather than discrete or graded scores. This criterion enables the measurements to be analyzed by parametric statistics. Quantitative measurements also avoid ceiling and floor effects.

6. "Low-tech", robust and portability: If the PPA is to be used successfully in community setting, it needs to be "low-tech", robust, and portable.

The major strength of the PPA is that it uses a function-based and quantitative model. It provides a powerful tool for fall risk factor identification and the evaluation of interventions aimed at maximizing

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physical function (16). To date, studies examining the effects of exercise on fall risk have not used an outcome measure that is comparable to the PPA. Previous studies have typically assessed one or more of the following to evaluate fall risk: 1) postural stability using force platforms, such as centre of pressure analysis; 2) postural stability using a clinical test, such as standing on one leg; 3) performance of a functional task, such as the Timed Up and Go Test; 4) performance on a battery of tasks, such as the Berg Balance Scale 5) gait; and 6) muscle strength. However, these measures have one or more of the following limitations: 1) lack of predictive validity; 2) no established normative data; 3) does not allow the examination of the individual physiological domains of postural stability; 4) floor and ceiling effects, and 5) non-quantitative measurement (e.g., graded scores of the Berg Balance Scale).

2.1.5.2 Limitations of the PPA

The PPA does not evaluate established fall risk factors such as neuropsychological factors (e.g., cognitive impairment), adverse effects of psychoactive medications, and medical conditions associated with falls (e.g., postural hypotension or carotid sinus hypersensitivity). Lord and colleagues also acknowledge that to refine and enhance the PPA, validated assessments of depth perception, vestibular function, and leaning balance are desirable (16).

### 2.1.6 Exercise as a Mean of Fall Prevention

There is strong evidence for exercise as an effective mean of fall prevention. In this section, I detail the published exercise intervention studies that aimed to reduce fall risk factors and falls in older adults.

2.1.6.1. Ameliorating Fall Risk Factors

Several published studies to date have demonstrated that exercise can positively influence multiple amendable fall risk factors such as postural stability, muscle strength, coordination, and reaction time in community-dwelling older adults (10,11,63,68-75). For example, Lord et al. (10) demonstrated that a 12-month general community-based exercise program can improve postural stability, strength, and reaction time in older women (mean age = 71.6, SD = 5.4). Tables 3a (laboratory assessments of postural stability)

and 3b (clinical assessments of postural stability) summarize the randomized controlled trials that examined the effects of exercise on postural stability in community-dwelling older adults. Postural instability is often viewed as the key risk factor for falls. I searched MEDLINE database using the following key words: balance, exercise, and aged. This search was limited to studies published from 1990 to 2003 in the English language that used a randomized controlled trial design. I also cross-checked references from these papers and all those in my collection to try to include all relevant papers. From the search result, I focused on those trials of community-dwelling adults with a mean age of 60 years or older without neurological conditions (e.g., stroke) or musculoskeletal conditions (e.g., post hip replacement) that affect postural stability.

Table 3a. Randomized controlled trials of exercise intervention primarily using laboratory assessments of postural stability. Studies are listed in chronological order (with the most recent one listed first).

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| Barnett, 2003 (76) | 163 men and women aged over 65 years identified as at risk of falling. Mean age of exercisers = 74.4, SD = 4.9, and of controls = 75.4, SD = 6.0. | General exercise program included aerobic, balance, coordination, and resistance exercises. A similar home exercise program was also given.<br>Duration: 12 months<br>Frequency: 1x/week (formal class), 60 minutes/session | Total sway path with sway meter under 4 conditions:<br>1) EO on floor.<br>2) EC on floor.<br>3) EO on foam.<br>4) EC on foam.<br>Coordinated stability task.<br><br>Results: Exercises performed significantly better than controls on EO and EC on floor and coordinated stability track. |
| Jessup, 2003 (77) | 18 older women (mean age = 69.2, SD = 3.5). | Exercise program included balance, stair-climbing, and resistance exercises. Weight-bearing exercises (not resistance exercises) were performed with weighted vest.<br>Duration: 32 weeks<br>Frequency: 3x/week, 60 minutes/session<br>Intensity: resistance training = 75% of 1RM | Sway path using force platform:<br>1) Closed base.<br>2) Open base.<br>3) Tandem stance.<br><br>Results: Exerciser significantly improved compared with controls. |
| Steadman, 2003 (78) | 199 men and women aged 60 years and older with a Berg Balance Scale score of less than 45 (mean age = 82.7, SD = 5.6). Recruited from a multidisciplinary falls clinic. | Two types of interventions: conventional therapy (CT) and enhanced therapy (ET). CT consisted of assisted walking within parallel bars, assessment for mobility aids, stair practice, general bed mobility skills, and transfers. ET consisted of all components of CT plus additional balance exercises.<br>Duration: 4 weeks for CT; 6 weeks for ET<br>Frequency: 2x/week, 45 minutes/session | Balance Performance Monitor:<br>1) Sway number.<br>2) Sway frequency.<br>3) Mean balance.<br>4) Sway Area.<br>5) Sway path length.<br>Berg Balance Scale.<br><br>Results: No significant difference between the two groups. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| Carter, 2002 (74) | 93 women with osteoporosis between 65 to 75 years of age. Mean age of exercisers = 69.6, SD = 3.0 and of controls = 69.0, SD = 3.5. | A community-centre-based exercise program (Osteofit) suitable for people with osteoporosis. Program included resistance, balance, and stretching exercises.<br>Duration: 20 weeks.<br>Frequency: 2x/week, 40 minutes/session | 1) Sensory Organization Test.<br>2) Figure-of-eight.<br><br>Results: Exercisers performed significantly better on the figure-of-eight compared with the controls. No significant difference between the groups in SOT. |
| Day, 2002 (79) | 1090 men and women aged 70 years and older (mean age = 76.1, SD = 5.0). | Factorial design of three interventions: group-based exercise, home hazard management, and vision improvement (8 experimental groups). Exercise class included exercises to improve flexibility, leg strength, and balance. Supplemented by daily home exercise.<br>Duration: 15 weeks (formal class)<br>Frequency: 1x/week (formal class), 60 minutes/session | Total sway path with sway meter under 2 conditions:<br>1) EO on floor.<br>2) EO on foam.<br>Coordinated stability task.<br>Maximal balance range.<br><br>Results: After 18 months (trial period), maximal balance range did not change within exercisers but decreased significantly over time within the controls. |
| Chandler, 1998 (80) | 100 functionally impaired community-dwelling men and women (mean age = 77.6, SD = 7.6). | In-home program supervised by a physical therapist. Program included lower extremity resistance exercises using therabands or body mass.<br>Duration: 10 weeks<br>Frequency: 3x/week | 1) Maximum excursion of the COP in the medial-lateral plane using force platforms.<br>2) Functional reach.<br><br>Results: No significant difference between or within the two groups. |
| Malmros, 1998 (81) | 53 postmenopausal women with at least one spinal crush fracture and pains in the last 3 years. Mean age of exercisers = 65 | Physiotherapy-based home program. Program comprised of lumbar stabilization exercises.<br>Duration: 10 weeks | Chattexc Balance System:<br>1) Quiet standing EO and EC.<br>2) Tandem stance. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | and of controls = 68. | Frequency: 2x/week, 60 minutes/session | 3) Quite standing with platform tilt. |
| Wolf, 1997 (82) | 72 inactive community-dwelling men and women at least 70 years of age. Mean age for computerized training group = 77.7, SD = 6.5, of Tai chi quan = 77.7, SD = 5.6, and of education group (control) = 75.2, SD = 4.9. One of the FISCIT trials. | Three experimental groups: computerized balance training, Tai chi quan, and an education group (control).<br>Duration: 15 weeks<br>Frequency: 1x/week for computerized balance training and education group, 2x/week for Tai chi quan group, 60 minutes/session | Results: No significant difference between or within the two groups. Chattexc Balance System:<br>1) Quiet standing EO and EC.<br>2) Toes up (angular perturbation of 4° over 4 seconds) EO and EC.<br><br>Results: Computerized balance training improved the force plate measures but little change noted in the other two groups. |
| Wolfson, 1996 (63) | 110 healthy community-dwelling men and women (mean age = 79, SD = 5). One of the FISCIT trials. | Factorial design of two interventions: balance training only, resistance training only, both balance and resistance training, and control.<br>Duration: 3 months<br>Frequency: 3x/week, 45 minutes each for balance and resistance training<br>Intensity: resistance training = 70 to 75% of 1RM | 1) Loss of balance during SOT.<br>2) Functional base of support on force platform.<br>3) Single stance time.<br><br>Results: Balance training significantly improved all outcome measures compared with controls. |
| Lord, 1996 (70) | 112 community-dwelling older women (mean age = 71.2, SD = 5.4). | General exercise program that included aerobic exercises, balance activities, hand-eye and foot-eye coordination, and resistance exercises.<br>Duration: 12 months<br>Frequency: 2x/week, 60 minutes/session | 1) Maximal balance range.<br>2) Coordinated stability task.<br><br>Results: No significant difference between the two groups. Exercisers significantly improved performance in both balance tasks. Controls demonstrated no improvement. |
| Lord, 1995 (10) | 197 community-dwelling older women (mean age = 71.6, SD = 5.4). | General exercise program that included aerobic and resistance exercises, activities for balance, | Total sway path with sway meter under 4 conditions: |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | | flexibility, endurance, and hand-eye and foot-eye coordination.<br>Duration: 12 months<br>Frequency: 2x/week, 60 minutes/session | 1) EO on floor.<br>2) EC on floor.<br>3) EO on foam.<br>4) EC on foam.<br><br>Results: Significantly greater number of exercisers made distinct balance improvements (i.e., 10% reduction) in EO and EC on floor than controls. |
| Hu and Woollacott, 1994 (83) | 24 men and women between 65 to 90 years of age. The mean age of the exercisers = 75.3, SD = 8.3, and of controls = 75.9, SD = 8.1. | Platform-based training that selectively manipulated sensory inputs from the visual, vestibular, and somatosensory systems.<br>Duration: 10 hours,<br>Frequency: 10 days in a 15-day period, 60 minutes/session | 1) Average RMS of COP (in AP plane) during four conditions:<br>Double stance, EO<br>Double stance, EC<br>Double stance, EO with sway-referenced support surface.<br>Double stance, EC, with sway-referenced support surface.<br>2) Number of falls during platform assessment.<br>3) Single stance with EO and EC.<br><br>Results: Exercisers significantly improved on the performance of the single stance compared with controls. Exercisers demonstrated significant improvement in 5 of the 8 platform training conditions. |
| Lord, 1994 (68) | 84 older adults between 50 to 75 years of age. Mean age of exercisers = 62.4, SD = 6.3 and of controls = 72.7, SD = 5.7. | General exercise program that included walking, flexibility, and resistance training exercises.<br>Duration: 10 weeks<br>Frequency: 2x/week, 60 minutes/session | Total sway path with sway meter under 4 conditions:<br>1) EO on floor.<br>2) EC on floor. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | | | 3) EO on foam. |
| | | | 4) EC on foam. |
| | | | Results: Statistical analyses examined within-group effect only. Improved performance on EC on floor, EO and EC on foam. No significant improvement in the controls. |
| Judge, 1993 (84) | 21 community-dwelling older women between 62 to 75 years of age (mean age = 68, SD = 3.5). | A "vigorous" program of lower-extremity strengthening, walking, and postural control exercises (Tai chi movements). Control group performed flexibility exercises only.<br>Duration: 6 months<br>Frequency: 3x/week, 20 minutes of walking/session<br>Intensity: resistance training = 70% of 1RM, 3 sets of 10 to 14 repetitions; walking = 70% of maximum heart rate | Average displacement of COP during four conditions:<br>1) Double stance with feet together EO.<br>2) Double stance with felt together EC.<br>3) Single stance with EO.<br>4) Forward lean single stance.<br><br>Results: No significant difference between the two groups, but exercisers improved 17% in single stance conditions while controls did not change. |
| Lichenstein, 1989 (85) | 50 community-dwelling older women aged more than 65 years old. Mean age of the exercisers = 77.5, SD = 7.5, and of controls = 75.9, SD = 7.5. | Exercise program consisted of stretches, static and dynamic exercises, walking, and response exercises.<br>Duration: 16 weeks<br>Frequency: 3x/week, 60 minutes/session | 1) COP area.<br>2) Average radial area.<br>3) Velocity under 4 conditions:<br>EO double stance.<br>EC double stance.<br>EO single stance.<br>EC single stance. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | | | Results: No significant difference between groups in double stance conditions. In single stance, exercisers had significantly smaller areas compared with controls with EO, but larger areas with EC. |

Table 3b. Randomized controlled trials of exercise intervention primarily using clinical assessments of postural stability. Studies are listed in chronological order (with the most recent one listed first).

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| LaStayo, 2003 (86) | 21 frail men and women between 70 to 93 years of age (mean age = 80.2). Random assignment? | Two experimental groups: traditional resistance training (TRAD) and eccentric resistance training (ECC). ECC group exercised on a recumbent, high-force eccentric, leg cycle ergometer. TRAD exercised with weight machines and free weights.<br>Duration: 11 weeks<br>Frequency: 3x/week, 10 to 20 minutes/session<br>Intensity: Gradual increase in training intensity using the Borg rating of perceived exertion (ECC); 6 to 8 repetitions (TRAD) | Berg Balance Scale.<br><br>Results: No significant difference between the groups. Significant improvement within the ECC group. |
| Latham, 2003 (87) | 243 frail men and women (mean age = 79.1, SD = 6.9). | Factorial design of two interventions: resistance training, resistance training and vitamin D supplementation, vitamin D supplementation, and control. Home resistance training consisted of a quadriceps exercise program using adjustable ankle cuff weights.<br>Duration: 10 weeks<br>Frequency: 3x/week<br>Intensity: resistance training = 60 to 80% of 1RM; vitamin D supplementation = 1 single oral dose of 300,000 IU | Berg Balance Scale.<br><br>Results: There was no effect of resistance training or vitamin D supplementation on the Berg Balance Scale. |
| Shigematsu, 2002 (88) | 38 health women between 72 to 82 years of age. Mean age of exercisers = 78.6, SD = 4.0 and of controls = 79.8, SD = 5.0. | Dance-based aerobic exercise.<br>Duration: 12 weeks<br>Frequency: 3x/week, 60 minutes/session<br>Intensity: individual's age-specific heart rate and rating of perceived exertion corresponding to the lactate threshold | 1) Single stance EO and EC.<br>2) Functional reach.<br><br>Results: Significant improvement within the exercisers in single stance EC and functional reach. No significant difference between the two groups in single stance EO. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| Barrett, 2002 (89) | Older men and women aged 60 years and older. Mean age of resistance training = 66.6 and of flexibility training = 69.9. | Group-based exercise programs. Resistance training (8 to 10 exercises) used free weights.<br>Duration: 10 weeks<br>Frequency: 2x/week | Functional reach test.<br><br>Results: Resistance training significantly improved functional reach compared with flexibility training. |
| Kronhed, 2001 (90) | 30 community-dwelling men and women between 70 to 75 years of age. | Balance training consisted of ordinary-life balance tasks, vestibular habituation, and ball exercises and station training. Mean age of exercisers = 73, SD = 2 and of controls = 73, SD = 2.<br>Duration: 9 weeks<br>Frequency: 2x/week, 60 minutes/session | 1) Single stance EO and EC.<br>2) Single stance while turning head.<br>3) Walking forward 30 m while turning head.<br>4) Rhomberg EO and EC.<br>5) Sharpened Rhomberg EO and EC.<br><br>Results: Significant improvement within the exercisers in single stance EC, single stance while turning head, and 30 m walk. Controls significantly decreased in the walking-forward test compared with exercisers. |
| Schlicht, 2001(91) | 24 community-dwelling older men and women 60 years of age and older (mean age = 72, SD = 6.3). | Resistance training of the lower body.<br>Duration: 8 weeks<br>Frequency: 3x/week<br>Intensity: 75% of 1RM, 2 sets of 10 reps | Single stance EC balance time.<br><br>Results: No significant difference between the two groups. |
| Yates, 2001 (92) | 37 community-dwelling older men and women between 67 to 90 years of age. Mean age of exercisers = 76 and of controls = 78. | Intervention group received fall risk education, exercise programming, nutritional counselling and/or referral, and environmental hazard education. Exercise program (4-page brochure) focused on improving strength, coordination, balance, and mobility through 19 chair-based exercises.<br>Duration: 10 weeks<br>Frequency: 3x/week | Tinetti Balance Assessment.<br><br>Results: Exercisers significantly improved their balance performance compared with the controls. |
| Buchner, 1997 (93) | 106 sedentary community-dwelling men and women between 68 to 85 years of age | Four experimental groups: cycling, walking, aerobic movement exercise group, and control.<br>Duration: 3 months | 1) Walking speed on a 17cm 6-meter balance beam.<br>2) Distance walked on an 8.5 cm 6-meter balance beam. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | with mild deficits in balance (mean age = 75). One of the FISCIT trials. | Frequency: 3x/week, 60 minutes/session Intensity: 75% of heart rate reserve | 3) Balance on AP tilt board and omni-directional tilt-board. 4) Sway area per second and average radius of sway over 22 seconds using force platforms (EO and EC).<br><br>Results: The distance walked on narrow beam improved in dose-response manner (cycle, 3%; walking, 7%; aerobic movement, 18%). Other balance measures did not improve with exercise. |
| Buchner, 1997 (94) | 105 community-dwelling men and women between 68 to 85 years of age with mild balance deficits (mean age = 75). One of the FISCIT trials. | Factorial design of two interventions: endurance training (cycle), resistance training, endurance and resistance training, and control. Duration: 24-26 weeks Frequency: 3x/week, 60 minutes/session Intensity: endurance training = 75% of heart rate reserve; resistance training = 50% of 1RM (1st set) & 75% of 1RM (2nd set), 2 sets of 10 reps | 1) Ability to walk on a 17cm 6-meter balance beam. 2) Ability to walk on an 8.5 cm 6-meter balance beam. 3) Balance on AP tilt board and omni-directional tilt-board. 4) Ability to balance in parallel, semi-tandem, and tandem stances.<br><br>Results: No significant difference between or within the groups. |
| Campbell, 1997 (95) | 233 community-dwelling older women. Mean age of exercisers = 84.1, SD = 3.1, and of controls = 84.1, SD = 3.4. One of the FISCIT trials. | Individualized program of physical therapy (physiotherapist visited during the first two months of the study only); included resistance and balance exercises. Duration: 6 months Frequency: 3x/week | 1) Functional reach test. 2) 4-test balance test (double stance with feet together, modified tandem stance, tandem stance, and single stance).<br><br>Results: Exercisers demonstrated significant improvement in the 4-test balance test score compared with the controls. |
| Rooks, 1997 (96) | 131 community-dwelling men and women aged 65 years and older. Mean age of resistance | Three experimental groups: resistance training, walking, and control. The resistance training program was designed to strengthen hip and | 1) Maintain static balance up to 60 seconds in the following stances: Tandem stance. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | exercisers = 72.7, SD = 4.6, of walkers = 72.9, SD = 5.4, and of controls = 75.1, SD = 6.0. | knee extensors, ankle plantarflexors and dorsiflexors, and elbow flexors.<br>Duration: 10 months<br>Frequency: 3x/week. 45 minutes/walking session and 60 minutes/resistance training session<br>Intensity: Self-selected. 3 sets per exercise for resistance training. | Single stance EO and EC.<br>2) Timed forward tandem walk along a 10 feet solid line.<br><br>Results: Exercise intervention groups significantly improved their performance of tandem stance and single stance EC compared with controls. Resistance training significantly improved the performance of single stance EO compared with controls. |
| Verfaillie, 1997 (75) | 39 community-dwelling men and women between 65 to 83 years of age. Mean age of exercisers = 72.1, SD = 1.1, and of controls = 71.5, SD = 0.93. | Two experimental groups: resistance training using Fisher machines combined with balance and gait training (S&B group), and resistance training only (control).<br>Duration: 12 weeks<br>Frequency: 2x/week, 60 minutes/session<br>Intensity: resistance training = 80% of 1RM, 1 set of 10 repetitions | 1) Maintain static balance up to 10 seconds in the following stances:<br>Classic Rhomberg.<br>Sharpen Rhomberg.<br>Tandem Stance.<br>Single stance EO and EC.<br>2) Tandem walk forward and backward for a maximum of 10 steps.<br><br>Results: No significant difference between the two groups. Within the S&B group, significant improvement in the ability to hold several of the static and dynamic balance components, with significant increases occurring in the tandem stance and tandem walks. Control group did not improve significantly in any of the balance measures. |
| Nelson, 1994 (62) | 40 community-dwelling older women between 50 to 70 years of age. Mean age of exercisers = 57.3, SD = 6.3, and of controls = 61.1, SD = 3.7. | High-intensity resistance training using 5 different exercises.<br>Duration: 1 year<br>Frequency: 2x/week<br>Intensity: 80% of 1RM, 3 sets of 8 repetitions | Backward tandem walk over a 20-foot course.<br><br>Results: Exercisers significantly improved their ability to perform the backward tandem walk (time to complete course) compared with controls. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| Topp, 1993 (97) | 55 community-dwelling older adults aged 65 and older. Mean age of exercisers = 69.2, SD = 0.8, and of controls = 72.8, SD = 1.0. | Resistance training (12 exercises) using therabands. Duration: 12 weeks Frequency: 3x/week, 60 minutes/session Intensity: 1 set of 10RM and progressing to 2-3 sets of 10RM | 1) Single stance EO and EC. 2) Backward tandem walk for 8 feet. Results: No significant difference between the two groups. Both outcome measures significantly improved within the exercisers. |
| Jones, 1992 (98) | 48 community-dwelling older women between 57 and 93 years of age (mean age = 68). | Combination of resistance, endurance, flexibility, and balance activities. Duration: 16 weeks Frequency: 3x/week, 60-90 minutes/session | Tandem walk on a 10 feel long, 4 inches in width and height. Results: No significant difference between the two groups. Exercisers significantly improved after 16 weeks of training while controls demonstrated no improvements. |
| Johansson and Jarnlo, 1991 (99) | 34 healthy 70 year-old women. | Walking (changing directions and speed), dancing steps, and sitting to stand task. Duration: 5 weeks Frequency: 2x/week | 1) Single stance EO and EC (left and right). 2) Single stance with neck rotation (left and right). 3) Walking along a beam. 4) Walking a figure-of-eight. Results: Exercisers significantly improved their walking speed for 30 meters and figure-of-eight compared with controls. |

COP = centre of pressure; EO = eyes open; EC = eyes closed; RM = repeated maximum; SOT = sensory organization test.

Results from Table 3a and 3b suggest that balance exercises, including vestibular training, improve postural stability more than those interventions that omit balance exercises (i.e., resistance training only). However, in those studies where resistance training alone failed to improve postural stability, two of the studies had very small number of participants (84,91) and two had low to moderate training intensity (80,94). In contrast, high-intensity resistance training (80% of 1RM) alone was effective in improving postural stability in one study with adequate sample size and training duration (62). Thus, high-intensity resistance training alone (as distinct from resistance training using therabands or body mass) may be just as effective as balance exercises in improving postural stability. Additional studies are needed to further test this hypothesis.

To elicit a recovery response to postural instability requires the ability to generate force (i.e., muscle strength) in appropriate amount of time (i.e., reaction time). Thus, Table 4 summarizes the randomized controlled trials that examined the effects of exercise on muscular strength. Table 5 summarizes the trials that examined the effects of exercise on reaction time. I searched MEDLINE database using the following key words: strength (for Table 4), reaction time (for Table 5), exercise, and aged. These searches were also limited to studies published from 1990 to 2003 in the English language that used a randomized controlled trial design. I also cross-checked references from these papers and all those in my collection to try to include all relevant papers. From the search result, I focused on those trials of community-dwelling adults with a mean age of 60 years or older without conditions (e.g., stroke, polymyositis, and osteoarthritis of the knee) that affect muscle strength and/or reaction time (e.g., cognitive impairment).

Table 4. Randomized controlled trials of exercise intervention on muscular strength. Studies are listed in chronological order (with the most recent one listed first).

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| Barnett, 2003 (76) | 163 men and women aged over 65 years identified as at risk of falling. Mean age of exercisers = 74.4, SD = 4.9, and of controls = 75.4, SD = 6.0. | General exercise program that included aerobic, balance, coordination, and resistance exercises. A similar home exercise program was also given. Duration: 12 months Frequency: 1x/week (formal class), 60 minutes/session | Seated isometric knee extension strength (kg). Results: No significant difference between the two groups. |
| Jessup, 2003 (77) | 18 older women (mean age = 69.2, SD = 3.5). | Exercise program included balance, stair-climbing, and resistance exercises. Weight-bearing exercises (not resistance exercises) were performed with weighted vest. Duration: 32 weeks Frequency: 3x/week, 60 minutes/session Intensity: resistance training = 75% of 1RM | Mean score (kg) of 8 strength tests (biceps curl, chest press, overhead press, triceps extension, leg extension, leg curl, lumbar extension, abdominal flexion) using Nautilus-type machines. Results: No significant difference between the two groups. |
| LaStayo, 2003 (86) | 21 frail men and women between 70 to 93 years of age (mean age = 80.2). Random assignment? | Two experimental groups: traditional resistance training (TRAD) and eccentric resistance training (ECC). ECC group exercised on a recumbent, high-force eccentric, leg cycle ergometer. TRAD exercised with weight machines and free weights. Duration: 11 weeks Frequency: 3x/week, 10 to 20 minutes/session Intensity: Gradual increase in training intensity using the Borg rating of | 1) Knee extension isometric strength (N) measured with a dynamometer at 45° of knee flexion. 2) Vastus Lateralis muscle fiber cross-sectional area. Results: ECC exercisers significantly improved strength (60%) compared with TRAD exercisers. Both groups significantly improved muscle fiber cross-section area (ECC = 60%, TRAD = 41%). |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | | perceived exertion (ECC); 6 to 8 repetitions (TRAD) | |
| Latham, 2003 (87) | 243 frail men and women (mean age = 79.1, SD = 6.9). | Factorial design of two interventions: resistance training, resistance training and vitamin D supplementation, vitamin D supplementation, and control. Resistance training consisted of a quadriceps exercise program using adjustable ankle cuff weights (at home). Duration: 10 weeks Frequency: 3x/week Intensity: resistance training = 60 to 80% of 1RM; vitamin D supplementation = 1 single oral dose of 300,000 IU | Seated maximal isometric knee extensor strength (kg). Results: There was no effect of resistance training or vitamin D supplementation on knee extensor strength. |
| Barrett, 2002 (89) | Older men and women aged 60 years and older. Mean age of resistance training = 66.6 and of flexibility training = 69.9. | Group-based exercise programs. Resistance training (8 to 10 exercises) used free weights. Duration: 10 weeks Frequency: 2x/week | 1) Isometric biceps strength (N). 2) Isometric quadriceps strength (N). Results: No significant difference between the two groups. |
| Carter, 2002 (74) | 93 women with osteoporosis between 65 to 75 years of age. Mean age of exercisers = 69.6, SD = 3.0 and of controls = 69.0, SD = 3.5. | A community-centre-based exercise program (Osteofit) suitable for people with osteoporosis. Program included resistance, balance, and stretching exercises. Duration: 20 weeks. Frequency: 2x/week, 40 minutes/session | Seated maximal isometric quadriceps strength (kg) of the dominant leg. Results: Quadriceps strength significantly increased among exercisers compared with controls. |
| Day, 2002 (79) | 1090 men and women aged 70 years and older (mean age = 76.1, SD = 5.0). | Factorial design of three interventions: group-based exercise, home hazard management, and vision improvement (8 experimental groups). Exercise class included exercises to | Seated maximal isometric quadriceps strength (kg) of the dominant leg. Results: Significant improvement in strength among exercisers after 15 weeks of the program. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | | improve flexibility, leg strength, and balance. Supplemented by daily home exercise. Duration: 15 weeks (formal class) Frequency: 1x/week (formal class), 60 minutes/session | |
| Shigematsu, 2002 (88) | 38 health women between 72 to 82 years of age. Mean age of exercisers = 78.6, SD = 4.0 and of controls = 79.8, SD = 5.0. | Dance-based aerobic exercise. Duration: 12 weeks Frequency: 3x/week, 60 minutes/session Intensity: individual's age-specific heart rate and rating of perceived exertion corresponding to the lactate threshold | 1) Half-squat position (s). 2) Hand-grip strength (kg). Results: No significant difference between the two groups. |
| Schlicht, 2001(91) | 24 community-dwelling mean and women 60 years of age and older (mean age = 72, SD = 6.3). | Resistance training of the lower body (6 exercises). Duration: 8 weeks Frequency: 3x/week Intensity: 75% of 1RM, 2 sets of 10 repetitions | 1RM assessments of each exercise (leg extension, inner thigh press, outer thigh press, glut press, leg press, and ankle press) every 2 weeks. Results: For each of the 6 exercises, strength significantly increased among the exercisers compared with the controls. |
| Yates, 2001 (92) | 37 community-dwelling older men and women between 67 to 90 years of age. Mean age of exercisers = 76 and of controls = 78. | Intervention group received fall risk education, exercise programming, nutritional counselling and/or referral, and environmental hazard education. Exercise program (4-page brochure) focused on improving strength, coordination, balance, and mobility through 19 chair-based exercises. Duration: 10 weeks Frequency: 3x/week | Lower extremity power calculated by one's ability to generate power from a seated to a standing position. Results: Exercisers significantly improved lower extremity power compared with the controls. |
| Takeshima, 2000 (100) | 30 older women between 60 to 75 years of age. Mean age of | Water-based exercise program. It included resistance and endurance-type | A hydraulic-resistance machine measured peak torque (Nm) of: |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | exercisers = 69.3, SD = 45 and of controls = 69.3, SD = 3.3. | exercises.<br>Duration: 12 weeks<br>Frequency: 3x/week, 70 minutes/session | 1) Knee extension/flexion.<br>2) Shoulder press/pull.<br>3) Chest press/pull.<br>4) Lumbar flexion/extension.<br><br>Results: Strength significantly increased in the exercisers compared with the controls – knee extension (8%), knee flexion (13%), chest press (7%), chest pull (11%), shoulder press (4%), shoulder pull (6%), and back extension (6%). |
| Taaffe, 1999 (101) | 46 community-dwelling men and women between 65 to 79 years of age. Mean age of EX1 = 68.5, SD = 3.6, of EX2 = 69.4, SD = 3.0, of EX3 = 71.0, SD = 4.1, and of controls = 68.9, SD = 3.6. | Four experimental groups: high-intensity resistance training 1 (EX1), 2 (EX2), or 3 (EX3) days per week and a control group. Resistance training consisted of 8 exercises targeting major muscle groups of the upper and lower body.<br>Duration: 24 weeks.<br>Frequency: 1-3x/week depending on group<br>Intensity: 80% of 1RM, 3 sets of 8 repetitions | Dynamic muscle strength (1RM) using isotonic equipment every 4 weeks.<br><br>Results: For each of the 8 exercises, strength significantly increased among the exercisers compared with the controls. There was no difference among the three exercise groups at any measurement interval. |
| Chandler, 1998 (80) | 100 functionally impaired community-dwelling men and women (mean age = 77.6, SD = 7.6). | In-home program supervised by a physical therapist. Program included lower extremity resistance exercises using therabands or body mass.<br>Duration: 10 weeks<br>Frequency: 3x/week | Isokinetic and isometric strength (Nm; Cybex) of the:<br>1) Bilateral knee extensors/flexors.<br>2) Ankle dorsiflexors/plantarflexors.<br><br>Results: Exercisers demonstrated significant improvement in all strength measures, except for dorsiflexors, compared with the controls. |
| Buchner, 1997 (94) | 105 community-dwelling older adults between 68 to 85 years of age with mild balance deficits | Factorial design of two interventions: endurance training (cycle), resistance training, endurance and resistance | Isokinetic (Nm) strength of muscles around the hip, knee, ankle, and elbow joints assessed at 6 and 9 months. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | (mean age = 75). One of the FISCIT trials. | training, and control.<br>Duration: 24-26 weeks<br>Frequency: 3x/week, 60 minutes/session<br>Intensity: endurance training = 75% of heart rate reserve; resistance training = 50% of 1RM (1st set) & 75% of 1RM (2nd set), 2 sets of 10 reps. | Results: The resistance training group demonstrated significant increases in isokinetic strength in all muscle groups except the ankle at 6 months. The endurance and resistance training group also demonstrated increases in strength, but only statistically significant at the knee joint. The endurance training group did not increase in strength, except at the knee joint. |
| Campbell, 1997 (95) | 233 community-dwelling older women. Mean age of exercisers = 84.1, SD = 3.1, and of controls = 84.1, SD = 3.4. One of the FISCIT trials. | Individualized program of physical therapy (physiotherapist visited during the first two months of the study only); included resistance and balance exercises.<br>Duration: 6 months<br>Frequency: 3x/week | Knee extensor strength assessed by an electronic dynamometer.<br><br>Results: No significant difference between the two groups. |
| Rooks, 1997 (96) | 131community-dwelling men and women aged 65 years and older. Mean age of resistance exercisers = 72.7, SD = 4.6, of walkers = 72.9, SD = 5.4, and of controls = 75.1, SD = 6.0. | Three experimental groups: resistance training, walking, and control. The resistance training program was designed to strengthen hip and knee extensors, ankle plantarflexors and dorsiflexors, and elbow flexors.<br>Duration: 10 months<br>Frequency: 3x/week. 45 minutes/walking session and 60 minutes/resistance training session<br>Intensity: Self-selected. 3 sets per exercise for resistance training. | 1) 1RM (kg) assessment of knee extensors.<br>2) Hand grip strength assessed by dynamometer.<br><br>Results: Resistance training significantly improved strength compared with both walking and controls. No significant changes in hand grip strength were seen in any of the groups. |
| Verfaillie, 1997 (75) | 39 community-dwelling older adults between 65 to 83 years of age. Mean age of exercisers = 72.1, SD = 1.1, and of controls = 71.5, SD = 0.93. | Two experimental groups: resistance training using Fisher machines combined with balance and gait training (S&B group), and resistance training only (control). | 1RM (kg) assessment (using weight machines) of:<br>1) Leg press.<br>2) Shoulder press.<br>3) Chest press.<br>4) Abdominal press. |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | | Duration: 12 weeks<br>Frequency: 2x/week, 60 minutes/session<br>Intensity: resistance training = 80% of 1RM, 1 set of 10 repetitions | 5) Latissimus dorsi pull-down.<br><br>Results: Both groups significantly improved strength with no between-group difference. |
| Wolfson, 1996 (63) | 110 healthy community-dwelling men and women (mean age = 79, SD = 5). One of the FISCIT trials. | Factorial design of two interventions: balance training only, resistance training only, both balance and resistance training, and control.<br>Duration: 3 months<br>Frequency: 3x/week, 45 minutes each for balance and resistance training<br>Intensity: resistance training = 70 to 75% of 1RM | Summed isokinetic torque (Nm/kg) of eight lower extremity movements.<br><br>Results: Resistance training significantly increased summed isokinetic torque by a mean of 1.1 Nm/kg, SD = 0.1. |
| Lord, 1995 (10) | 197 community-dwelling older women (mean age = 71.6, SD = 5.4). | General exercise program that included aerobic and resistance exercises, activities for balance, flexibility, endurance, and hand-eye and foot-eye coordination.<br>Duration: 12 months<br>Frequency: 2x/week, 60 minutes/session | Isometric maximal strength (kg) of:<br>1) Ankle dorsiflexors.<br>2) Knee extensors.<br>3) Knee flexors.<br>4) Hip extensors.<br>5) Hip flexors.<br><br>Results: Significantly greater number of exercisers demonstrated improved strength (i.e., 10% increase) on all five measures. |
| Skelton, 1995 (102) | 52 healthy women aged 75 years and older. Median age of exercisers = 79.5, range = 76 to 93 and of controls = 79.5, range = 75 to 90. | Progressive resistance training program using rice bags (1 to 1.5 kg) or elastic tubing.<br>Duration: 12 weeks<br>Frequency: 3x/week, 1 supervised session and 2 unsupervised home sessions; 60 minutes/supervised session<br>Intensity: 3 sets of 4-8 repetitions | 1) Isometric knee extensor strength (N/kg).<br>2) Isometric elbow flexor strength (N).<br>3) Handgrip strength (N).<br>4) Leg extensor power (W).<br><br>Results: Exercisers demonstrated significant improvement in all three strength measures compared with the controls. No significant difference in leg extensor |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | | | power between the two groups. |
| Lord, 1994 (68) | 84 older adults between 50 to 75 years of age. Mean age of exercisers = 62.4, SD = 6.3 and of controls = 72.7, SD = 5.7. | General exercise program that included walking, flexibility, and resistance training exercises. Duration: 10 weeks Frequency: 2x/week, 60 minutes/session | Seated maximal isometric quadriceps strength (kg) of the dominant leg. Results: Statistical analyses examined within-group effect only. Significant improvement in the exercisers. No significant improvement in the controls. |
| Nelson, 1994 (62) | 40 community-dwelling older women between 50 to 70 years of age. Mean age of exercisers = 57.3, SD = 6.3, and of controls = 61.1, SD = 3.7. | High-intensity resistance training using 5 different exercises. Duration: 1 year Frequency: 2x/week Intensity: 80% of 1RM, 3 sets of 8 repetitions | 1RM assessment (kg) of: 1) Double leg press. 2) Knee extension. 3) Lateral pull-down. Strength (kg) at 16 on the Borg scale for: 4) Back extension. 5) Abdominal flexion. Results: Change (increase) in strength over the year was significant between the two groups. Increases in strength ranged from 35.2 to 76.3% for the resistance training group. |
| Judge, 1993 (84) | 21 community-dwelling older women between 62 to 75 years of age (mean age = 68, SD = 3.5). | A "vigorous" program of lower-extremity strengthening, walking, and postural control exercises (Tai chi movements). Control group performed flexibility exercises only. Duration: 6 months Frequency: 3x/week, 20 minutes of walking/session Intensity: resistance training = 70% of 1RM, 3 sets of 10 to 14 repetitions; walking = 70% of maximum heart rate | 1RM assessment (kg) of: 1) Knee extension. 2) Seated leg press. Results: The exercise group significantly increased knee extension strength compared with the controls. No significant difference in seated leg press between the two groups. |

RM = repeated maximum; SOT = sensory organization test.

Table 5. Randomized controlled trials of exercise intervention on reaction time. Studies are listed in chronological order (with the most recent one listed first).

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| Barnett, 2003 (76) | 163 men and women aged over 65 years identified as at risk of falling. Mean age of exercisers = 74.4, SD = 4.9, and of controls = 75.4, SD = 6.0. | General exercise program that included aerobic, balance, coordination, and resistance exercises. A similar home exercise program was also given. Duration: 12 months Frequency: 1x/week (formal class), 60 minutes/session | Simple reaction time (msec) of the foot. Results: No significant difference between the two groups. |
| Shigematsu, 2002 (88) | 38 health women between 72 to 82 years of age. Mean age of exercisers = 78.6, SD = 4.0 and of controls = 79.8, SD = 5.0. | Dance-based aerobic exercise. Duration: 12 weeks Frequency: 3x/week, 60 minutes/session Intensity: individual's age-specific heart rate and rating of perceived exertion corresponding to the lactate threshold | Hand reaction time (cm). Results: No significant difference between the two groups. |
| Rooks, 1997 (96) | 131community-dwelling men and women aged 65 years and older. Mean age of resistance exercisers = 72.7, SD = 4.6, of walkers = 72.9, SD = 5.4, and of controls = 75.1, SD = 6.0. | Three experimental groups: resistance training, walking, and control. The resistance training program was designed to strengthen hip and knee extensors, ankle plantarflexors and dorsiflexors, and elbow flexors. Duration: 10 months Frequency: 3x/week. 45 minutes/walking session and 60 minutes/resistance training session Intensity: Self-selected. 3 sets per exercise for resistance training. | Simple reaction time (msec) of the right lower extremity. Results: Resistance training significantly improved reaction time compared with controls. |
| Lord, 1995 (10) | 197 community-dwelling older women (mean age = 71.6, SD = 5.4). | General exercise program that included aerobic and resistance exercises, activities for balance, flexibility, endurance, and hand-eye and foot-eye coordination. | Simple hand reaction time (msec). Results: Significantly greater number of exercisers demonstrated improved |

| First Author & Date | Participant | Exercise Intervention | Outcome Measure & Results |
|---|---|---|---|
| | | Duration: 12 months, 60 minutes/session<br>Frequency: 2x/week | reaction time (i.e., 5% reduction) compared to the controls. |
| Lord, 1994 (68) | 84 older adults between 50 to 75 years of age. Mean age of exercisers = 62.4, SD = 6.3 and of controls = 72.7, SD = 5.7. | General exercise program that included walking, flexibility, and resistance training exercises.<br>Duration: 10 weeks<br>Frequency: 2x/week, 60 minutes/session | Simple reaction time of the foot (msec).<br><br>Results: Statistical analyses examined within-group effect only. Significant improvement in the exercisers. No significant improvement in the controls. |
| Whitehurst, 1991 (103) | 15 older women (mean age = 65). | Stationary cycling.<br>Duration: 8 weeks<br>Frequency: 3x/week, 35 to 40 minutes/session. | 1) Simple reaction time.<br>2) Choice reaction time.<br><br>Results: No significant difference between the two groups. |
| Panton, 1990 (104) | 49 men and women between 70 to 79 years of age. Mean age of walk/jog = 71.8, SD = 1.9, of resistance = 72.2, SD = 2.5, and of controls = 72.1, SD = 3.0. | Three experimental groups: walk/jog, resistance training, and control.<br>Duration: 6 months (26 weeks)<br>Frequency: 3x/week, 30-40 minutes/session<br>Intensity: walk/jog = target for 75 to 85% of maximal heart rate reserve; resistance training = 8 to 12 repetitions, training to volitional muscular fatigue | Dominant hand:<br>1) Total reaction time (msec).<br>2) Pre-motor time (msec).<br>3) Motor time (msec).<br>4) Speed of movement (msec).<br><br>Results: No significant difference between the three groups. |

Results from Table 4 suggest that supervised resistance training (i.e., group-based or one-on-one supervision) is effective in improving muscular strength in community-dwelling older adults. Unsupervised home resistance training programs (95,105) and aerobic- or balance-based programs (63,88) (i.e., non-resistance training) were not effective. There is, however, a risk of musculoskeletal injury with resistance training (87). Thus, adequate warm-up and cool-down periods are essential components of any resistance training program. Results shown in Table 5 do not suggest that exercise alone can effectively improve reaction time in older adults.

2.1.6.2. Preventing Falls

Recent randomized controlled trials of exercise interventions significantly reduced falls (79,82,94,95,106). The Frailty and Injuries: Cooperative Studies of Intervention Techniques (FICSIT) trials -- a research initiative sponsored by the National Institute on Aging and the National Institute for Nursing Research, was a landmark series of trials. These independent randomized controlled trials were conducted in seven United States centres. Each had an exercise component that varied from site to site and lasted from 10 weeks to 36 weeks. Two nursing homes and five community-dwellings were involved and study centre enrolment ranged from 100 to 1323 participants. The minimum age for enrolment was 60 to 75 years. The exercise component varied across centres in terms of frequency, intensity, duration, and type. The preplanned meta-analysis of these seven trials (N = 2328) found that the adjusted fall incidence ratio for the treatment arms, including general exercise, was 0.90 (95% CI 0.81 to 0.99). For those treatment arms that included balance training, the adjusted fall incidence ratio was 0.83 (95% CI 0.70 to 0.98) (106). Thus, the incidence of falls was reduced by approximately 10% in those undertaking any exercise and by about 17% in those undertaking balance exercise.

Two individual FICSIT trials demonstrated a significant effect of exercise on falls. Wolf et al. (107) reported that Tai Chi reduced the risk of multiple falls by 47.5% (risk ratio of 0.525, p = 0.01) in 70 years or older community-dwelling adults. Buchner et al. (94) found that exercise had a protective effect on the risk of falling (relative hazard of 0.53, 95% CI 0.30 to 0.91) in 105 older adults with at least mild deficits in

strength and postural stability. Interestingly, exercise did not reduce fall rates in the intervention group but fall rates increased in the control group, which is consistent with age-related physiological decline (see Section 2.1.4). Thus, exercise may play a role in fall prevention by slowing deterioration.

New Zealand geriatrician John Campbell and colleagues at the University of Otago (95) also demonstrated a reduction in falls and associated injuries with a home-based physical therapy intervention of resistance exercises and balance retraining. In this study, 232 community-dwelling women aged 80 years and older were randomized either to an individually tailored program of physical therapy in the home or to usual care with social visits. After one year, the relative hazard for the first four falls in the exercise group compared with the control group was 0.61 (95% CI 0.52 to 0.90) (95). After two years, the relative hazard for all falls during the two years for the exercise group compared with the control group was 0.69 (95% CI 0.49 to 0.97) (108). The relative hazard for a fall resulting in a moderate or severe injury was 0.63 (95% CI 0.42 to 0.95).

The above home-based exercise program was also effective in reducing falls in men and women aged 75 years and older when delivered by community nurses (109). Specifically, falls were reduced by 46% (incidence rate ratio of 0.54, 95% CI 0.32 to 0.90) after one year. The fourth exercise trial to assess the effect of this home-based exercise program on falls in routine clinical practice, also provided a 30% reduction in falls (incident rate ratio of 0.70, 95% CI 0.59 to 0.84) in both men and women aged 80 years and older (110). The meta-analysis of these four trials (95,108-111) found that the home-based exercise program was most effective in reducing fall-related injuries in those 80 and older and resulted in a higher absolute reduction in injurious falls when offered to those with a history of a previous fall (112).

Day et al. (79) provide more recent support for the role of exercise in fall prevention. In their randomized factorial trial of fall prevention among community-dwelling adults aged 70 years or older, these Australian researchers assessed the effectiveness of three interventions (group-based exercise, home hazard management, and vision improvement) delivered to eight experimental groups defined by the presence or absence of each intervention (79). The main outcome measure was time to first fall

ascertained by an 18-month fall calendar. The results indicated that group-based exercise was the most potent single intervention (incident rate ratio of 0.82, 95% CI 0.70 to 0.97) and the reduction in falls among this group appears to have been associated with improved postural stability.

A 12-month community-based exercise program that included exercises to improve balance, coordination, aerobic capacity, and muscle strength also significantly reduced falls in older adults aged over 65 years at risk of falling (76). The once weekly exercise class was supplemented with a home-based program that mirrored the class content. Within the trial period, the rate of falls in the intervention group was 40% lower than that of the control group (incident rate ratio of 0.60, 95% CI 0.36 to 0.99).

In the 2002 Cochrane review of interventions for preventing falls in elderly people (113), interventions that deemed to likely be beneficial were the home program of muscle strengthening and balance retraining (95) and the Tai Chi group exercise intervention (107) described above. I note that the studies by Day et al. (79) and Barnett et al. (76) were not included in this Cochrane review.

Thus, exercise appears to be an effective mean of fall prevention. However, as noted previously, no published studies have delineated the specifics of exercise prescription for optimal fall reduction (fall risk factors and falls), such as frequency, intensity, type, and duration. In regards to fracture prevention, no published studies have delineated the specifics of exercise prescription for optimal fall (risk factor and/or falls) reduction *and* enhanced bone health. Furthermore, no follow-up studies have determined if the effects of exercise on both fall risk *and* bone health persists beyond the intervention period in older adults.

## 2.2 Bone Biology, Mechanics, and Osteoporosis

In this section, I provide an overview of bone biology, the processes of bone change and adaptation in general, bone mechanics, and changes in bone properties associated with aging. This section concludes by describing the specific adaptations of bone to mechanical loading, with a special focus on mature bone via studies in animal models.

## 2.2.1 Bone Biology

The two primary functions of bone are to provide mechanical integrity and to take part in calcium homeostasis. In addition, bone is a primary site of haematopoiesis (114). This thesis focuses on the mechanical role of bone.

Bone consists of an organic component (20-25% by weight), an inorganic or mineral component (70% by weight), and water (5% by weight). Ninety-eight percent of the organic component is composed of Type I collagen and a variety of non-collagenous proteins, with bone cells accounting for the remaining 2% of the organic phase (115). The inorganic component is 95% crystalline calcium hydroxyapatite (115).

Three cell types are found in bone, osteoblasts, osteocytes, and osteoclasts. Osteoblasts are bone-forming cells. They synthesize osteoid, the protein component of bone tissue. With time, an osteoblast becomes either a flat lining cell or an osteocyte (115). Osteocytes are mature bone cells embedded deep within small bone cavities called osteocytic lacunae. Osteocytes within the mineralized matrix are in direct communication with each other and surface osteoblasts through their cellular processes. The primary function of the osteoblast-osteocyte network is considered to be mechanosensory (i.e., transducing stress signals to biological activity) (116). Osteoclasts are bone cells responsible for bone resorption. The function of bone cells is outlined further in Section 2.2.2 (Bone Turnover).

Bone exists in two forms: woven and lamellar. Woven, or primary bone, is a coarse-fibered tissue that does not show any uniform orientation of the collagen fibers. Lamellar bone is a highly organized material with respect to the stress orientation of the collagen fibers. Anatomically, woven and lamellar bone are organized into cortical and trabecular bone compartments (115).

The skeleton is comprised of cortical bone and trabecular bone. Cortical bone forms the outer layer of long bones or vertebrae and has four times the mass of trabecular bone (115). Cortical bone is usually subject to bending and torsional forces, as well as compressive loads (117). There are two types of surfaces to cortical bone, one on its inner side -- known as the endosteum, the other on its outer side -- known as the periosteum. Cells lining the endosteum are metabolically active and participate in bone

formation and resorption. The inner layer of the periosteum, known as cambium, contributes to appositional bone growth during bone development and increasing the diameters of long bones with aging (118). Trabecular bone is found primarily at the ends of long bones and in the cuboid bones such as the vertebrae. Trabecular bone has an ideal structure to resist compressive loads (117).

### 2.2.2 Bone Turnover

Three distinct processes modulate bone growth and maintenance throughout life: growth, modeling, and remodelling. Growth refers to the increase in bone length and width from birth to the end of adolescence. This process is mediated by hormones and is genetically predetermined (119). Detailed discussion of growth is outside the scope of this thesis, but the reader is referred to relevant review articles (120-122).

Modeling is an organized bone cell activity that allows bone growth and augments bone strength by independent bone resorption (osteoclast activity) and formation (osteoblast activity) drifts (123). In macro-modelling, the strength of bone is enhanced by increasing mass and improving local architecture. Bone is formed without prior resorption, resulting in a net gain of bone. Mini-modeling involves a change in orientation of trabeculae only, without a change in frank mineralization or bone size (118,123).

Remodelling is a continuous process that allows bone to adapt throughout life and modify its material properties in response to the mechanical demands placed on it (115). Remodelling also serves to maintain the biomechanical competence of the skeleton by preventing the accumulation of fatigue damage. Remodelling is different from modelling as the former involves the coupled activity of osteoclasts and osteoblasts that results in non-significant changes in the shape or density of bone (under normal conditions). Basic multicellular units (BMU), small packets of osteoblasts and osteoclasts, are responsible for remodelling through a sequence of events that include osteoclast formation, osteoclast activation, resorption of bone, osteoblast activation, and formation of new bone (124-127). The discussion of biochemical markers of bone remodelling is beyond the scope of this thesis, but the reader is referred to the recent review article by Seibel (128).

The balance between modeling and remodelling differs between the growing and non-growing skeleton. Modelling is dominant in the former while remodelling is dominant in the latter (118).

### 2.2.3 Bone Mechanics

The mechanical properties of bone can be described at two levels: material and structural properties (129). Bone strength is influenced by both its material and structural properties. Material properties refer to properties of the bone at the tissue level. Structural properties refer to the characteristics of the bone as a whole unit. The material properties and the structural properties are inextricably related by the architecture of bone (130). In this section, I provide an overview of basic bone biomechanics.

2.2.3.1 Basic Concepts

The concepts of stress and strain are essential for understanding the biomechanics of bone. These terms are used to describe the phenomenon whereby, when a force is applied to bone, the bone will not only be deformed from its original dimensions but an internal resistance will be generated to the counter applied force (129). Stress, the force applied per unit area, can be classified as tensile, compressive, or shear (Figure 2) (131). Stress is measured in units of Newtons per square meter ($N/m^2$) or Pascals (Pa). Tension is produced in bone when two forces are directed away from each other along the same straight line. Compression results from two forces that are directed towards each other. Shear occurs when two forces are directed parallel to each other but not along the same line. In nature, these three basic stress types often combine to produce a variety of complex loading configurations and lead to different fracture patterns. For example, bending stress results from a combination of tensile and compressive forces.

Strain is the deformation of a material and refers relative change in bone dimensions. Strain is calculated by dividing the change in dimension by the original dimension and therefore, has no units. Stiffness is the amount of force required to deform a structure and is represented by the slope of the stress-strain curve (Figure 3). This slope is also known as Young's modulus of elasticity and the relationship between stress and strain and Young's modulus (stiffness) is expressed as:

$$\epsilon = S/E$$

where $\in$ is strain, S is stress and E is Young's modulus.

The quality of bone can influence the magnitude of stresses and strains generated, so stress applied to

well-mineralized bone tissue will results in small strains (129).
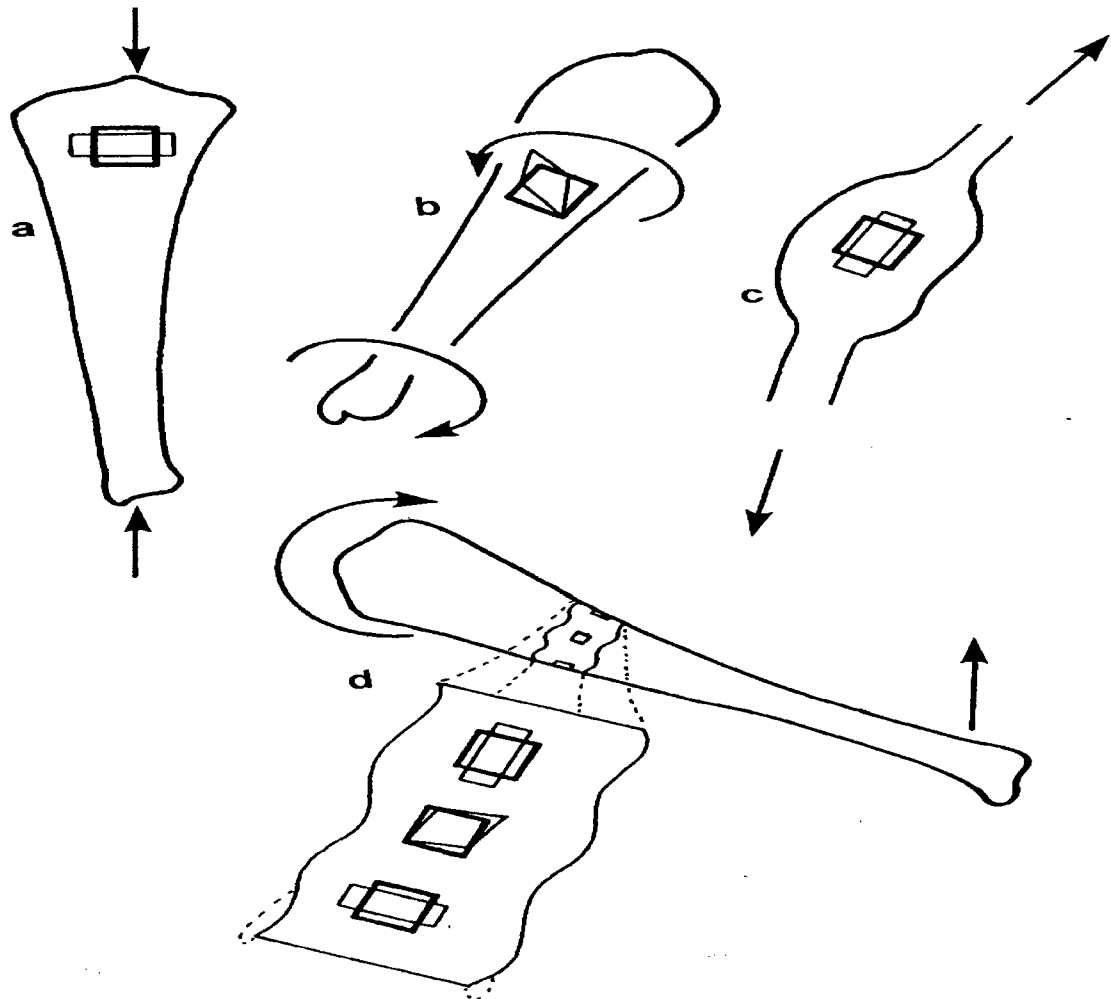


Figure 2. Schematic diagrams of loads on bones, shown by arrows, and the resulting deformations. The deformations are: a) compression, b) torsion, c) tension, and d) bending. In d), the deformations are shown on a piece of bone unwrapped from a whole bone. The lower part shows tension, the middle shows shear, and the top shows compression.
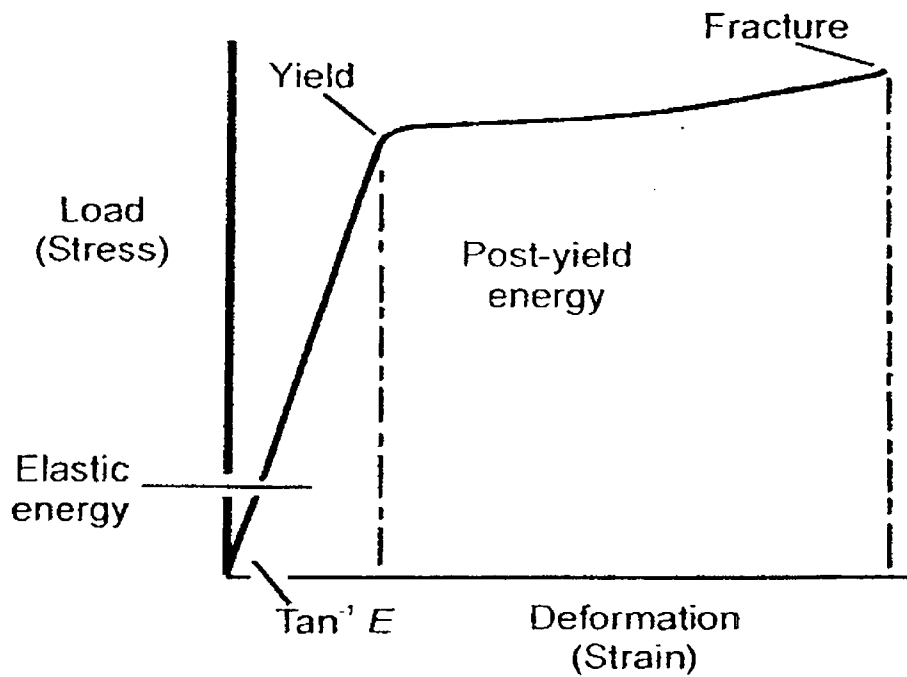
Figure 3. Typical load-deformation (stress-strain) curve.

2.2.3.2 Material Properties of Bone

The organic and inorganic components of bone determine its material properties. The organic

component, primarily type 1 collagen, provides tensile strength. The inorganic component, mineral, resists

compressive forces (131).

The material properties of bone are typically defined by performing standardized mechanical tests

on uniform, machined specimens of intact bone (129). Material properties of bone are independent of its

size and shape (132). Material properties are influenced by composition factors such as mineral density,

collagen content, and ash fraction. Other factors such as collagen cross-linking, collagen fiber orientation,

mineral crystal size, and the microstructural organization also influence material properties (132). There

are four basic (material) mechanical properties of bone that can be derived from the stress-strain curve:

stiffness, energy-absorptive capacity, strength, and deformation. Stiffness of bone tissue is measured as

Young's modulus of elasticity (slope of the stress-strain curve). Stiff materials have a steeper slope than

more compliant ones. The area under the stress-strain curve is the energy absorbed by the specimen

(energy absorptive capacity). The total energy stored at the point of fracture defines the toughness of the

bone material. Material strength of bone is determined by calculating the maximum stress (ultimate strength) at the point where the bone fails. The strength of bone is anisotropic, that is, it is different when measured in different directions (130). For example, the static strength of bone is about 150 MPa in tension and about 230 MPa in compression. In general, bones resist loads best when the loads are oriented in the customary direction (129).

2.2.3.3 Structural Properties of Bone

The structural properties of bone are determined on whole sections of intact bone whose normal geometry has been maintained (129). The relationship between applied load and deformation for the whole bone is defined by a load-deformation curve. This curve is analogous to the stress-strain curve (Figure 3).

The mechanical behaviour of whole bone is dependent not only on the mass of the tissue and its material properties, but also on its geometry and architecture (i.e., structural properties) (129). Structural properties of whole bone include size, shape (i.e., periosteal dimensions), cortical wall thickness, cortical cross-sectional area, total cross-sectional bone area (CSA), and trabecular architecture (e.g., size, number, and orientation). Specifically, the mechanical behaviour of whole bone depends largely on the cross-sectional distribution of cortical bone and the horizontal/vertical disposition and integrity of trabecular bone (133).

The stiffness and strength of whole bone depends greatly on the spatial disposition of its material throughout its cross-section with respect to the bending or torsional axis in question (133). Thus, bending and torsional responses of long bones are controlled by the moments of inertia of the cross-section. The cross-sectional moment of inertia (CSMI; I) and the polar moment of inertia (J) can be considered indicators of bending stiffness and torsional stiffness, respectively. Both moments of inertia are expressed in the unit of $mm^4$ and mathematically as:

$$I = \Pi / 4 \ (r_o^4 - r_i^4) \qquad\qquad J = \Pi / 2 \ (r_o^4 - r_i^4)$$

Where $r_o$ is the radius measured to outer surface of the cortical wall and $r_i$ is the radius measured to the inner surface of the cortical wall. A perfect cylindrical shaft is assumed in the calculation of moments of inertia.

It is evident from the mathematical equations that small deposits of new bone at the periosteal surface or minor periosteal expansion of the cortical bone would increase both moments of inertia considerably. Thus, maximum moments of inertia are achieved when cross-sectional bone area is as far from the neutral axis as possible. According to Seeman (134), given the unique biomechanical advantage of the deposition of bone on the periosteal surface, the periosteal-lining cell is an obvious target for pharmaceutical therapy. However, although an outward shift of bone can compensate for a decrease in bone mass in terms of torque and bending, it does not compensate for it during axial loading.

At any site, trabeculae tend to be preferentially oriented in the direction of principle stresses to allow the bone to be both stronger and stiffer in these particular directions (135). The importance of trabecular orientation in relation to principle stresses was evident when vertebrae of similar apparent density were loaded in the superior-inferior and medial-lateral directions (136). The superior-inferior trabecular orientation provided twice as much strength when loaded in that direction as compared to medial-lateral loading.

### 2.2.4 Age-Related Changes in Bone

In this section, I discuss the age-related changes in both the material and structural properties of bone.

2.2.4.1 Changes in Bone Material

The elastic modulus and strength of cortical and trabecular bone decrease with age in both men and women (137). There are significant decreases with age in the amount of deformation and energy absorbed by cortical bone before fracture. Furthermore, the energy required to fracture cortical bone under impact loading decreases three-fold between the ages of 3 and 90 (138). Thus, age-related changes in cortical bone result in a more brittle material (137). Specifically, there is an age-related decline in the area

within the cortex that is occupied by circumferential lamellar bone, and an increase in the number of

Haversian systems and their fragments (139). Aging also results in a decrease in the radial closure rate of

osteons, an increase in the diameter of the Haversian canals, a decrease in osteon wall thickness, and an

increase in the number of resorption cavities that are aborted in the reversal phase and remain unfilled.

Each of these contributes to an increase in cortical porosity (139).

Similar age-related changes in material properties occur in trabecular bone. For example, the ash

density of vertebral trabecular bone declines approximately 50% from ages 20 to 80, while the material

properties (compressive elastic modulus, ultimate stress, and energy to failure) decrease by 70 to 90%

(140). Specifically, aging is associated with a gradual decline in the ability of the osteoblast teams to refill

the resorption cavities that ultimately results in thinning of the trabeculae (139). However, rapid,

postmenopausal loss of trabecular bone is not the result of osteoblast insufficiency but rather due to

enhanced osteoclastic resorption. With the increase in bone turnover rate that is secondary to estrogen

deficiency, the number of resorption sites that are active per unit time is increased and the osteoclasts dig

cavities that perforate the trabeculae that are ultimately removed (139). This results in a greater age-

related loss of trabecular number and connectivity with age in women than in men.

2.2.4.2 Changes in Bone Structure

Age-related changes in the material properties of bone tissue are accompanied by a redistribution

of both cortical and trabecular bone. There is consensus that the general pattern of adaptation of the

appendicular skeleton with age includes endosteal resorption and periosteal apposition of bone (137,141-

144). As a result, the diameter of the cortical bone increases but the width of the cortical shell decreases,

and these structural changes ultimately augment bone's ability to resist bending and torsional by increasing

the moments of inertia (132). For example, a 10% outward shift of bone can compensate for a 30%

decrease in bone mass in terms of bending and torque (145). Beck et al. (146) provided the following

specific example of this phenomenon on the section modulus: Expanding a 2 cm wide endocortical

diameter of a 3 cm wide tubular bone by 10% (2 mm) will reduce areal BMD by about 16%. However, a

mere 0.83 mm simultaneous increase in the subperiosteal diameter would maintain the original section modulus and thus, a net loss of about 9% in areal BMD can occur without any real change in bending or torsional strength.

Men have greater periosteal apposition during aging than women do but the amount of endocortical bone that is resorbed is similar in men and in women (134). There is an inverse correlation between serum estradiol level and periosteal apposition suggesting that there is periosteal-envelope-specific effect on the cellular activity that determines the architecture of bone (134). It is postulated that while estrogen inhibits periosteal apposition during puberty, estrogen deficiency (i.e., menopause) removes a constraint on periosteal apposition, which increases and partially compensates for endocortical bone loss (134). Estrogen is also thought to preserve bone on bone surfaces near marrow (147). These dual effects of estrogen appear to be regulated by different molecular pathways. The suppressive effect of estrogen at the periosteum is largely due to signalling through the beta isoform of the estrogen receptor (ERbeta) whereas the preservative effects of estrogen on trabecular and endocortical surfaces rely on signalling through estrogen receptor alpha (ERalpha) (147).

An association between the extent of endocortical resorption and periosteal apposition during the 15 years after menopause was recently reported (142). After adjustment for differences in bone size, women with greater endocortical bone loss had greater periosteal bone formation. A rather surprising finding in this study was that the cortical thickness was undiminished.

### 2.2.5 Bone Adaptation to Mechanical Loading

As this thesis is particularly concerned with exercise (a form of mechanical loading), the mechanism whereby such loading influences bone is discussed in some detail. Major concepts that underpin bones' response include mechanotransduction and the influence of various dimensions of strain.

The skeleton's ability to adapt to functional demands is well-recognized and Wolff's law describes this phenomenon (148). The primary premise of Wolff's law is that bone seeks to optimize its structure in response to the level of activity to which it is subjected. How bone responds to mechanical stresses is an

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example of mechanotransduction. Mechanotransduction is a general biological process that refers to the conversion of a biophysical force into a cellular response. In bone, mechanotransduction occurs via four steps: mechanocoupling, biochemical coupling, transmission of signal, and effector cell response (116). Aging probably affects each of these steps (149). Mechanocoupling is the transduction of mechanical force applied to bone into a local mechanical signal perceived by a sensor cell. Possible sensors of mechanical signals include osteoblasts, lining cells, and osteocytes. The populations of these cell types decrease with advancing age (150), which reduces the mechanical sensitivity of bone (149). Biochemical coupling is the transduction of local mechanical signal into a biochemical signal and, ultimately, gene expression. Transmission of signal occurs from the sensor cell to the effector cell and likely involves paracrine factors, such as prostaglandins or insulin-like growth (IGF-I) factors (116). The efficiency of the effector cells is determined, to some extent, by their microenvironment. Bone concentrations of both IGF-I and its binding proteins decrease with age in rats (151), suggesting a change in the microenvironment of osteoblasts with age. Also, the bioactivities of cell attachment proteins like fibronectin, thrombospondin, and osteopontin are degraded with age (152). It is likely that age-related changes in these proteins affect osteoblastic activity (149). The effector cell elicits responses according to three primary variables: strain magnitude, strain rate, and strain distribution.

2.2.5.1 Strain Magnitude

Strain magnitude is the amount of relative change in bone length under mechanical loading (153). Animal studies show that bone adapts to optimize strain. Rubin and Lanyon (153) demonstrated a 40% increases in the CSA of the ulna of mature male turkeys with peaks strains greater than 1000 microstrain, and strains exceeding 4000 microstrain. Cross-sectional area increased by periosteal and some endosteal new bone formation. These results provide the fundamental basis for the mechanostat theory (124).

A window of normal mechanical usage, called the minimal effective strain (MES), is an essential concept in mechanostat theory. This theory postulates that bone modelling occurs when mechanical signals in bone exceed the upper boundary of MES (2000 to 3000 microstrain) to change its structure to

reduce the local strains to below the MES. On the other hand, bone resorption occurs when mechanical signals in bone is at the lower boundary of MES (50 to 200 microstrain).

2.2.5.2 Strain Rate

Strain rate is the rate at which strain develops and releases (154). The importance of strain rate to skeletal response to loading was highlighted by Lanyon and Rubin (154) in the avian ulna. They assessed remodelling activity in the avian ulna under three conditions: 1) disuse alone, 2) disuse with superimposed continuous compressive load, and 3) disuse interrupted by a short daily period of intermittent loading. Both non-loaded and statically loaded bones demonstrated increases in endosteal diameter and intra-cortical porosity after 8 weeks, producing a similar decrease in CSA in both groups. In contrast, intermittently loaded bones showed a 24% increase in CSA.

2.2.5.3 Strain Distribution

Strain distribution refers to the way strain is distributed across a section of bone (155). Unusual strains of uneven distributions are more important for osteogenesis than strain repetitions or strain magnitudes that result from everyday activity (155). Lanyon et al. (155) demonstrated in skeletally mature sheep radius (after removal of supporting ulna) that very small strain changes within the bone's customary strain range stimulate osteogenesis. Specifically, the area of the remaining radius was increased by periosteal new bone formation until it equalled the total area of bone in the radius and ulna in the contralateral limbs despite the fact that the absolute levels of functional strains at the bone forming surfaces were less than normal near the end of the experimental period.

2.2.5.4 The Response to Mechanical Loading in Mature Animals

While animal studies have demonstrated that bone in healthy young animals is extremely sensitive to changes in strain magnitude (153), rate (154), and distribution (155-157), aging appears to change (increase) the minimum effective strain for bone formation (149,158).

Using an externally loadable, functionally isolated turkey ulna preparation, Rubin et al. (158) subjected the ulna of one-year-old and three year-old turkeys to 300 cycles per day of a load regimen

generating a strain of 3,000 microstrain for 8 weeks. Areal properties of bone and histomorphometry were studied on both the experimental and intact control ulna. While bone CSA in the one year-old animal increased by 30.2% ( $\pm$ 7.8%) as compared with the intact contralateral control ulna, the areal properties of the older skeleton remained essentially unchanged (-3.3% $\pm$ 7.5%). The increase in CSA of the young bones was due to increased periosteal mineralizing surface. In contrast, the old turkeys demonstrated an absence of periosteal labelling. However, the three-year old turkey bones showed greater osteonal mean wall thickness and a lengthened intracortical remodelling period when compared with the young animals.

Data suggest that both the periosteal and endocortical surfaces of mature bone are less responsive to mechanical loading than younger bone (149). Mechanical loads varying from 30 to 64 N were applied to the tibia of 43, 19-month old rats using a four-point bending apparatus for 15 days (149). Bone formation rates were measured on the periosteal and endocortical surfaces of the tibial midshaft using double-label histomorphometry. Bone formation rates from the 19-month-old rats were compared with 9-month-old rats. The periosteum of old rats had a higher threshold for activation by mechanical loading, but after activation occurred, the cells had the same capacity to form woven bone as the periosteum in younger adult rats. The endocortical bone forming surface in the old rats was 5-fold less than relative bone forming surface measured in younger adult rats under similar loading conditions. In addition, the relative bone formation rate in the old rats was 16-fold less than that in younger adults rats at an applied load of 64 N. These data strongly support that aging shifts the mechanical loading threshold, or the minimum effective strain for bone formation.

Raab et al. (159) measured bending strength of the femur in 2.5 and 25 month old rats to determine bone mechanical properties after a 10-week program of treadmill running. Although these investigators concluded that training effects were not limited by age, the strategy by which the young and mature bones adapted to exercise stress was quite different and consistent with the observations of Rubin et al. (158). The increase in breaking force of the young femur was proportional to an increase in cross-sectional moment of inertia, with no significant alterations in ultimate stress. In contrast, the old rats

demonstrated increases in bone fat-free dry weight and ultimate stress without an associated increase in CSMI. Thus, although the ability of the old rats to activate surface modelling to bring about an increase in CSMI appears limited compared with the younger rats, older rat bone can still initiate some intracortical adaptation.

Thus, evidence from animal studies undeniably demonstrates that growing bone has a greater capacity to add new bone to the skeleton than does the bone of adult animals. Furthermore, young and mature bone adapt to loading via different mechanisms (160). Young bone has a greater potential for periosteal expansion than aging bone, allowing it to adapt more rapidly and efficiently to the need for increased strength. Mature bone can increase its mass by increasing osteonal mean wall thickness (160). From both histomorphometric and biomarker data, mechanical loading appears to promote bone health in the mature skeleton by promoting bone formation (161,162) and suppressing resorption (161).

## 2.3 Bone Mineral Measurement

Accurate and precise measurements of bone underlie quantitative bone physiology research in humans. Thus, in this section, I define bone parameters provided by dual energy X-ray absorptiometry (DXA) and peripheral quantitative computed tomography (pQCT). I also discuss the advantages and limitations of both instruments. This section ends with a brief discussion of three emerging methods of bone measurement (MRI, QUS, and QCT) not used in this thesis.

### 2.3.1 Dual-Energy X-Ray Absorptiometry (DXA)

DXA was first introduced in 1987 and uses X-ray beams of two peak energies produced by a variety of techniques to optimize separation of the mineralized and soft tissue components of bone. The earliest instruments used radioisotopes to provide photons but present day densitometers use X-ray tubes to permit greater precision, reduce radiation, eliminate drift, and shorten scanning times compared with the isotope sources. The degree to which the X-ray beam is attenuated depends on the energy of the incident photons, the length of the path of the beam, and the material properties of the tissue being studied (163). There are over 6000 DXA systems in use worldwide (164).

Currently, DXA is the best-known procedure to measure bone mass with acceptable accuracy and precision. Its determination of bone "mass" (i.e., how much mineralized bone tissue is within a bone organ or region) is reported as areal bone mineral density (BMD) in grams/cm$^2$ or bone mineral content (BMC) in grams. It is important to note that areal BMD as measured by DXA is not synonymous with true three-dimensional volumetric BMD. Areal BMD was introduced to normalize BMC, which is proportional to bone and body size (165). Areal BMD also has the advantage that measurement errors, due to slight movement or differences in bone edge detection, tend to affect both BMC and bone area in the same direction and thus, are minimized (166). DXA derived areal BMD is a good estimator of fracture risk (166,167) (see Fracture Prediction in Section 2.3.1.1).

I note that the mathematical expression of areal BMD (BMC/bone area) is based on an assumption of direct proportionality between BMC and bone area (such as BMC = k * bone area; where k is areal BMD). There is, however, no theoretical basis for this assumed relationship between BMC and bone area (166). Thus, if areal BMD is used to report bone mineral when the relationship between BMC and bone area is not one of simple direct proportion, part of its variation within a population will be due to differences in bone size between individuals (166). Therefore, although areal BMD partially reduces the effect of bone size on bone mass, it does not take into account the true volume. For a constant volumetric bone density, a larger vertebra would typically yield higher areal BMD results than a smaller one (Figure 4).
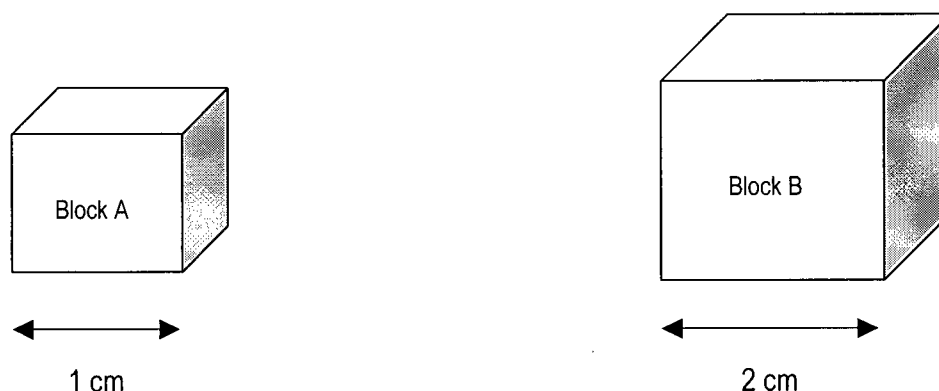
| | Block A | Block B |
|---|---|---|
| Total material density (g/cm$^3$) | 1 g/cm$^3$ | 1 g/cm$^3$ |
| Total material (bone mineral content) (g) | 1 gram | 8 grams |
| Bone area (cm$^2$) | 1 cm$^2$ | 4 cm$^2$ |
| Areal bone mineral density (g/cm$^2$) | 1 g/cm$^2$ | 2 g/cm$^2$ |

Figure 4. Areal BMD by DXA is greatly size dependent. Even though the two blocks are made of the same material, the large block has twice the areal BMD as measured by DXA (118).

2.3.1.1 Strengths of DXA

The major strengths of DXA as a measurement tool are its:

1. Acceptable accuracy.

2. High precision.

3. Low level of radiation.

4. Standardized measurement procedures.

5. Established population norms in several races (e.g., Caucasian, Black, and Asian).

6. Ability to assess clinically relevant regions in both the axial and appendicular skeleton, such as the lumbar spine, total proximal femur and its sub-regions, and total body.

7. Ability to predict fracture risk.

## Accuracy

Accuracy is generally defined as the DXA measured value expressed as a percentage of the specified BMC of a skeletal phantom. Accuracy can also be defined against the ash content of cadaver specimens, but this is rarely done except in laboratory settings. For fracture risk stratification a low ratio of accuracy error to biological variation is needed (165).

Bone mineral content as measured by DXA correlated well, but systematically underestimated the weight of cadaver specimens by approximately 5 to 9% (118). Ho et al. (168) assessed the accuracy of DXA of the lumbar spine using 11 cadavers (L2-L3). DXA derived areal BMD and BMC were compared with measured density and ash content respectively. The accuracy error in determining areal BMC in lumbar vertebrae with DXA was found to be about 9%. A strong correlation was also observed between areal BMD and ash density (r = 0.881).

## Precision

When assessing the suitability of a measurement technique for follow-up purposes, the most important parameter is precision (169). Precision is defined as the degree of variability found in multiple measures of the same item. Precision is usually expressed as a coefficient of variation (CV). Coefficient of variation is based on the size of the standard deviation relative to the mean, expressed as a percentage. To decide whether a follow-up measurement provides evidence of a significant and clinically relevant change, knowledge of the precision errors of the technique is required (170). For a single follow-up measurement, the smallest change that can be regarded as statistically significant at the 95% confidence level is approximately 3 times the precision error (171). Thus, bone densitometry with DXA is eminently suited for the measurement of changes over time in an individual because of its low precision error (165).

A number of short-term precision studies have been conducted on DXA and are summarized by Patel et al. (170). The short-term precision for the spine ranges from 0.60 to 1.34% and 0.79 to 2.0% for the femoral neck (170). Areal BMD, in vivo, precision was 0.66% for the total body, 0.56% for the lumbar spine, 0.53% for the total proximal femur, 0.84% for the trochanteric region, and 1.1% for the femoral neck

(Hologic QDR 4500) in the University of British Columbia Bone Health Research Laboratory. The long-term precision of DXA (over 7 years) in 40 postmenopausal women was established as 1.65% at the lumbar spine, 2.48% for the femoral neck, and 1.57% for the total hip (170). Areal BMD was measured at 0, 6, and 12 months and thereafter every 12 months up to 7 years. Long-term precision was determined by linear regression (areal BMD by time). Each residual was expressed as the percentage difference from predicted areal BMD and the validity of assuming linear change with time was checked using the mean residuals for each visit number.

Subject repositioning influences the precision of DXA. A study using eight subjects demonstrated that both hip rotation and hip abduction had an influence on precision (172). Specifically, the mean variations in areal BMD of the femoral neck, Ward's triangle and trochanter were 2.7, 4.1 and 1.7%, respectively, with the subjects' feet internally rotated by 0, 13 and 27 (customary position) degrees. The mean variations in areal BMD scanned with the leg in the customary position and abducted $\pm$ 6 degrees from the conventionally used position were 3.6, 2.8 and 1.6% for the same respective regions. Thus, exact repositioning is necessary to achieve precision, in vivo, of less than 1% for monitoring changes in areal BMD longitudinally. Another study using 24 female cadavers demonstrated that femoral anteversion (external rotation of the hip joint) was associated with a significant elevation in femoral neck areal BMD of +2.8% (range –5.3 to 9.8%).

**Fracture Prediction**

In a prospective study of 8,134 women, Cummings et al. (6) found that a 2.6-fold increase in risk (of hip fracture) for each standard deviation decrease in femoral neck areal BMD. As highlighted by British endocrinologist John Kanis (173), DXA predicts fracture better than blood cholesterol levels predict heart attacks.

In 1990, Tom Beck and colleagues (174) introduced an interactive computer program, known as Hip Structural Analysis (HSA) in an attempt to improve the predictive value of the proximal femur mineral data for osteoporotic fracture risk assessment. This program derives femoral neck geometry from raw

bone mineral image data to estimate hip strength using single plane engineering stress analysis (174). HSA-computed femoral neck CSA and CSMI on an aluminum phantom were in excellent agreement with actual values (r greater than 0.99) (174). HSA-computed cross-sectional properties (CSA and CSMI) of 3 femoral (neck) cadaver specimens compared acceptably with those sequential computed tomography derived measurements; the discrepancy between the two methods averaged less than 10%. Finally, HSA-predicted strength in tension was strongly correlated (r = 0.89) with the actual breaking strength of femur cadaver specimens.

2.3.1.2 Limitations of DXA

As Jarvinen et al. (175) suggested in 1999, despite the many strengths of DXA, its use in longitudinal studies (such as exercise intervention studies) has some limitations. These include the two-dimensional nature of the images and its inability to distinguish the various bone components.

**Inherent Planar Nature**

As mentioned in Section 2.2.3, both material properties (e.g., Young's modulus of elasticity and volumetric density) and structural properties (e.g., cortical wall thickness, cross-sectional area, and trabecular architecture) contribute to the mechanical behaviour of whole bone. Yet, other than bone "mass", DXA provides no measure of either bone material or structural properties, which contribute to whole bone strength. As well, it can not differentiate between cortical and trabecular bone. Due to this latter limitation, the rates of bone loss reported using DXA include both types of bone. However, it may be important to determine the loss of cortical and trabecular bone separately to assess fracture risk. For example, true rates of bone loss differ for cortical and trabecular bone in the ultradistal radius of older women (176). Cortical bone loss averaged 0.41% per year versus a trabecular loss of 0.65% per year. Also, cortical bone loss as assessed by radiogrammetry, was 87% greater in postmenopausal women with vertebral compression fractures and 116% greater in those with Colles' fracture than in normal postmenopausal women (177). Thus, it may be more meaningful to examine the loss of cortical bone in the distal forearm when evaluating future Colles' fracture risk in postmenopausal women (177).

Jarvinen et al. (178) demonstrated in 13-week old rats that mechanical loading (sudden impact loading) could substantially improve the structural properties (cortical wall thickness) and mechanical characteristics (CSMI and breaking load) of the femur without simultaneous gain in BMC measured by DXA. Also, in a prospective exercise intervention study involving 250 postmenopausal women between the ages of 52 to 72 years, Adami et al. (13) assessed the effects of a training program designed to load the wrist. DXA was performed at the lumbar spine, proximal femur, and radius and pQCT at the proximal and ultradistal radius. After 6 months of exercise intervention, DXA demonstrated no significant training effects in areal BMD at any measured site. In contrast, pQCT measurement of the ultradistal radius showed a significant training effect in the cross-sectional area of cortical bone. These two studies highlight the insensitivity of DXA, due to its inherent planar nature, to the strategic realignment of bone morphology and redistribution of bone mass within a structure secondary to mechanical loading. These data provide the primary basis of Jarvinen et al.'s (175) argument that DXA may seriously underestimate the effects of mechanical loading on bone. Thus, despite the many benefits of DXA, the inherent planar and integrated nature of its measures renders a true geometric assessment of a bone impossible and bone strength estimations grossly approximate (179). Yet, these are key bone variables that are of current interest in exercise efficacy studies.

**Systematic Inaccuracies**

There are systematic inaccuracies inherent in DXA-derived areal BMD measurements, in vivo. The systematic inaccuracies originate from the "two-component limitation" of DXA. The valid applicability of DXA methodology is restricted to areal BMD determinations, in vivo, of bone sites that contain only one effective tissue component in addition to that of bone material over the entire scan region (180). This strict two-component DXA requirement, however, cannot be satisfied, in vivo, as both fat tissue and lean muscle tissue (two absorptiometrically different tissues) will always coexist in a DXA scan region of interest. As well, marrow - another absorptiometrically different tissue, exists in the intraosseous region.

In an extensive series of quantitative simulation studies replicating ideal DXA areal BMD measurements, in vivo, of typical and realistic lumbar vertebral and proximal femur sites (i.e., cadaver specimens), areal BMD inaccuracies as high as 20% or more occurred, especially in older individuals with substantial bone loss (180). The most important soft-tissue anthropometric determinants of the extent of bone site-specific systematic areal BMD inaccuracies reflected in DXA measurements, in vivo, are the ratio of the areal density of extraosseous fat to that of lean muscle tissue immediately surrounding the interrogated bone site. Another major influence is the extent of the specific yellow and/or red marrow within the region of interest. For example, the DXA-measured, in vivo, areal BMD value increases as the fat to lean muscle mass ratio increases in the extraosseous region. It is important to note that the rate of increase/decrease of areal BMD, in vivo, as a function of the increased/decreased ratio of fat to lean muscle tissue mass depends very much on what the true trabecular bone volume (TBV) may be. At identical bone sites, the smaller the true TBV value the higher the rate at which DXA-measured areal BMD changes with variations in the ratio of fat to lean muscle tissue mass (180). In addition, for any given true TBV value and ratio of fat to lean muscle tissue mass, the greater the yellow content of marrow, the greater will be the underestimation of areal BMD. These systematic inaccuracies can influence the results of exercise intervention studies where the fat to lean muscle mass ratio may significantly change secondary to the training stimulus, especially when a population of older osteoporotic individuals is involved!

It is also well known that aortic calcifications, osteoarthritis, spondylosis, and vertebral compression fractures can give falsely high lumbar spine areal BMD in P/A projection (165,181). Aortic calcification may be superimposed or juxtaposed on one or more lumbar vertebrae. If juxtaposed, calcification may lead to edge detection problems and result in lower areal BMD values. If superimposed, aortic calcification would inflate areal BMD values (181). Furthermore, vertebral compression fractures give falsely high areal BMD values without affecting BMC (165,182). In 57 postmenopausal women with osteoporosis aged 50 to 82 years, the average increase in areal BMD for fractured lumbar vertebrae was 0.070 g/cm$^2$ (182). The average z-score for fractured lumbar vertebrae was –1.62 compared to –2.26 for uncollapsed vertebrae.

As these conditions (aortic calcifications, osteoarthritis, spondylosis, and vertebral compression fractures) are prevalent in older adults, the use of P/A lumbar spine DXA scans to detect changes in areal BMD in this population may be misleading.

Lumbar spine DXA scans can also be obtained in a lateral (decubitus) position to allow the analysis to exclude the posterior (cortical) bone elements. Compared with the P/A lumbar DXA scans, this lateral spine DXA scan is more diagnostic (i.e., more sensitive) (183). With 40 to 60% of vertebral body bone mass being trabecular bone, a lateral approach which excludes the predominately cortical bone of the posterior elements is more sensitive to changes in bone mass (184). However, overlap of the iliac crest may substantially increase the measured bone density primarily at the level of L4, and ribs overlap L2 in almost all individuals (164). As well, the reproducibility of the lateral DXA measurements is poorer than P/A projections due to the greater thickness and nonuniformity of the soft tissue in the lateral projection (164). The development of the C-arm (a rotating arm) allows measurement of the lateral spine in the supine position, thereby reducing the limitations (reproducibility, obliquity, overlap of pelvis and rib) associated with the decubitus position (164,185). Supine lateral spine DXA may also be more capable of detecting serial bone mass changes than P/A spine DXA since the precision error of supine lateral technology is lower than decubitus lateral spine measurements (185,186).

In summary, DXA provides a measurement of bone mass (expressed as either grams/cm$^2$ or grams) that can be compared with established population norms. DXA results are strong predictors of clinical fracture (6,187) and vertebral body compressive strength (188). Thus, DXA does provide an indication of whole bone strength. However, measuring whole bone strength does not provide insight into the underlying mechanisms by which structural integrity is achieved (132). To fully appreciate the influence of drug therapy, exercise intervention, genetics and other variables of interest on bone, material, structural, and whole bone data would be ideal.

### 2.3.2 Peripheral QCT

The introduction of peripheral quantitative computed tomography (pQCT) provides an opportunity to investigate bone structure, in peripheral bone, where cortical bone is well represented and to assess trabecular and cortical bone separately. Early prototypes of the pQCT scanners used a radionuclide source, however, current scanners use an X-ray source (164). Bone mass measured by pQCT is expressed as volumetric BMD in grams/$cm^3$.

Peripheral QCT allows for volumetric density measurements of appendicular bone without superimposition of other tissues and provides an exact three-dimensional localization of the target volume (164). There are about 1000 pQCT systems in use worldwide (164), including 3 to 5 in Canada. They are used for research at present.

### 2.3.2.1. Precision

Peripheral quantitative computed tomography measurements are generally less precise than DXA measurements. The precision error, in vitro, is about 0.2% (CV) (179). The root mean square CV ($CV_{rms}$) values for the long bone, in vivo, ranged from 0.9% (distal tibia) to 2.7% (distal femur) for trabecular bone volumetric density, from 1.8% (distal femur) to 7.6% (distal radius) for trabecular area, from 2.0% (distal tibia) to 6.8% (proximal tibia) for cortical bone volumetric density, from 1.8% (distal femur) to 4.9% (proximal tibia) for cortical bone area, and from 4.2% (proximal shaft of humerus) for cortical area, and from 2.5% (midshaft of tibia) to 7.5% (proximal shaft of humerus) for stress-strain index (SSI in $mm^3$) (179). Also, Sievanen et al. (179) found no interoperator effect on precision.

### 2.3.2.2 Accuracy

The pQCT has moderate accuracy. Multiple slicing (e.g., 3 slices at the site of interest) is more accurate than single slicing. In a cadaver study 12 human radii were measured with pQCT and subsequently ashed. Takada et al. (189) found the correlation coefficient between pQCT total bone content (mg/mm) and ash weight with single slicing (2.5 mm) to be r = 0.87 and the accuracy error of 15.5%.

However, the correlation coefficient improved to r = 0.95 with an accuracy error of 9.7% after averaging the results of all three slices for each forearm.

## 2.3.2.3 An Alternative to DXA?

Due to its ability to offer many opportunities for the examination of bone biomechanics, pQCT is gaining popularity with researchers. For example, Jarvinen et al. (178) recommend that in every future bone study in which structural alterations may occur, DXA should be supplemented with pQCT, as the latter provides mechanically more relevant and detailed information. In addition to its ability to assess cortical bone and trabecular bone separately, and to provide volumetric BMD, pQCT provides other valuable information such as whole bone quality indices (e.g., SSI) and structural properties of bone (e.g., cortical wall thickness and cross-sectional area).

### Whole Bone Quality Indicators

Ferretti et al. (190) first introduced the bone strength index (BSI in $mm^4$ x $g/cm^3$) in 1996. BSI is estimated from CSMI x cortical volumetric BMD. Unlike CSMI, which does not consider bone material properties in estimating whole bone mechanical behaviour, BSI combines both material (cortical volumetric BMD) and structural (CSMI) variables into a single index for the estimation of bone strength. Axial BSI (xBSI) has been validated as a pQCT-derived indicator of bending strength in 103 rat femurs (190). It was correlated linearly (r = 0.94, $R^2$ = 0.89, p < 0.001) and very closely with the actual breaking force of rat femurs within a large range of values of CSMI and cortical density (190). This correlation was stronger than those obtained between breaking force and any of the two components of the BSI alone (CSMI, cortical volumetric BMD) or the DXA-derived areal BMD.

The Norland/Stratec pQCT instruments also provide an additional bone strength index for long bones -- the stress/strain index (SSI in $mm^3$). The SSI is the product of section modulus and cortical volumetric BMD (i.e., density-weighted section modulus). The section modulus is related to CSMI as both are geometrical indices that describe the bone distribution around the neutral axis of loading in bending and thus reflect the bending strength and stiffness of a bone, respectively (178). Section modulus is the ratio of

CSMl/y, where y is the distance from the centre of mass to the subperiosteal surfaces. Because the maximum stress in bending or torsion is on the outer (subperiosteal) surface, the structural component of strength is determined by the section modulus (191). SSI was proposed to reflect the long-bone strength more generally than BSI, but needs to be validated in future investigations (192). A study involving 91 healthy men and 88 women aged 20 to 79 years showed that SSI of the radius did not vary with age in men but decreased slightly in women after 52 years (193). However, SSI did not vary with age at the radial midshaft.

**Structural Properties**

The structural properties of bone assessed by pQCT include: cortical wall thickness, cross-sectional area, circumference of the endosteum, and circumference of the periosteum.

Based on the findings of recent prospective exercise intervention studies using pQCT, it appears only prudent to include pQCT in studies where structural changes, and consequently bone strength adaptation, may occur. For example, if Adami et al. (13) had not used pQCT to complement DXA measures in their six-month exercise intervention, the significant increase in ultradistal radius cortical bone CSA would have not been identified. Also, Uusi-Rasi et al. (194) demonstrated a significant 3.7% increase (95% CI 0.1 to 7.3%) in the ratio of cortical bone to total bone area in the distal tibia with a 12-month jumping exercise program involving postmenopausal women. The integrated DXA measures would not have highlighted this change in bone.

2.3.2.4 Limitations of pQCT

Despite its advantages, pQCT cannot be considered a replacement for DXA for the following reasons:

1.  pQCT is limited to assessing the appendicular skeleton. pQCT is generally considered to be unsuitable for assessing the proximal femur due to positioning discomfort. To my knowledge, there is currently only one published study involving Japanese women that assessed the proximal femur with pQCT (195).

2. Normative data is not currently available for pQCT measures.

3. It is not currently known whether pQCT measures predict future fractures. However, pQCT measures had poorer ability to discriminate women with fractures (vertebral, hip, or Colles' fractures) than measurements using DXA in a cross-sectional study (196).

4. Measurement procedures are not standardized. For example, different investigators use different methods for estimating the location of the same measurement site.

5. An error exists in the current Stratec (Stratec Medizintechnic GmbH, Pforzheim, Germany) analysis program for the calculation of cortical wall thickness, circumference of the endosteum, and circumference of the periosteum based on the real shape of the bone.

6. pQCT scans are subject to partial volume effect (PVE) errors (192). The source of error is in the determination of the bone areas based on the unavoidable inclusion of voxels that are not filled with mineralized tissue. The PVE may lead to underestimation of regional volumetric BMD measurements that may exceed 15% (192).

7. The precision of pQCT is lower than that reported for DXA. Due to the lower precision of the pQCT (compared with DXA), a prospective study using pQCT must have greater change in bone parameters before statistical significance at the 95% confidence level may be obtained compared with a study using DXA (for a single follow-up measurement)[1]. For example, Grampp et al. (197) demonstrated a precision error (with repositioning) in 20 postmenopausal osteoporotic women (aged 69 ± 8 years) of 2.1% for trabecular volumetric BMD of the radius. This is a large error relative to the mean decrease of 0.22% per year in trabecular volumetric BMD attributed to aging in the same study. Grampp et al. (197) therefore concluded that the sensitivity of standard volumetric BMD measurements by pQCT for the detection of age-related changes may not be very high.

Considering the advantages and limitations of both DXA and pQCT, including both bone measurements in longitudinal studies of bone health is recommended.

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[1] For a single follow-up measurement the smallest change that can be regarded as statistically significant at the 95% confidence level is approximately 3 times the precision error (171).

### 2.3.3 Other Methods of Bone Measurement

In addition to DXA and pQCT, other methods of assessing bone include magnetic resonance imaging (MRI), quantitative ultrasound (QUS), and quantitative computed tomography (QCT). These three methods will be outlined only briefly as they may provide future research opportunities but were not used in this thesis.

#### 2.3.3.1 Magnetic Resonance Imaging

Utilizing MRI to evaluate bone provides a radiation-free assessment of bone and muscle volume, and area. Although this modality has the potential to safely assess the magnitude of bone changes with exercise across the lifespan at a range of skeletal sites, quantification and standardization of MRI outcomes are still being developed (198).

#### 2.3.3.2 Quantitative Ultrasound

In recent years there has been an increased interest in the use of QUS for the assessment of skeletal status as it has the potential to provide information about bone architecture. As well, QUS is cheaper than DXA and like the MRI, QUS provides a radiation-free assessment of bone. However, it is not clear precisely what QUS measures. Its outcome measures include ultrasound transmission velocity (UTV in m/s) and the frequency dependency of the attenuation of ultrasound signal, called broadband ultrasound attenuation (BUA). Ultrasound transmission velocity is usually expressed as the quotient of the time taken to pass through the bone in question and the dimensions that it passed through. If the dimensions include soft tissue surrounding bone, the measure is called speed of sound (SOS). If it includes bone only, it is called ultrasound velocity through bone (UVB). It is assumed that both BUA and UTV are influenced by bone density and bone microarchitecture (118).

Two prospective studies demonstrated that calcaneal QUS measurements predicted fracture risk in postmenopausal women (199,200). However, others found that QUS measurements had very low sensitivity (15%) for identifying older women at risk of hip fracture (201). Laboratory studies using human

cadaveric specimens have shown that BUA and SOS of the calcaneus correlate strongly with proximal femur strength tested to failure (202).

2.3.3.3 Quantitative Computed Tomography

Quantitative computed tomography uses general-purpose CT scanners to provide true volumetric BMD generally of purely trabecular bone of the midvertebral body (184). Clinical results indicate that QCT can reliably evaluate and monitor osteoporosis and its various treatments. The greatest advantages of spinal QCT are the high precision of the technique (203), the high sensitivity of the vertebral spongiosa for fracture risk assessment, and the potential for widespread use. QCT has the ability to measure selectively the trabecular compartment of the vertebral body, which is more metabolically active than cortical bone. As trabecular bone is the first to respond to menopausal changes, spinal QCT has been recognized as a sensitive method with which to assess BMD changes in those with osteoporosis (184). Also, QCT measurements of trabecular bone density are independent of anthropometric parameters. However, QCT requires a higher radiation dose and longer imaging time than DXA, and its accuracy is substantially influenced by bone marrow (204).

## 2.4 Exercise and Bone Health in Postmenopausal Women

Regular physical activity helps to maintain bone health in the postmenopausal skeleton. In this section, I provide an overview of the condition of osteoporosis and examine the evidence for exercise, or physical activity, in the promotion of bone health in postmenopausal women. Relevant animal model studies are also discussed.

### 2.4.1 Osteoporosis

This section defines the condition of osteoporosis, describes the epidemiology and pathogenesis of this bone disease, and reviews its risk factors. I conclude by describing the common therapies for osteoporosis.

## 2.4.1.1. Definition

Osteoporosis is the one of the most prevalent chronic health conditions among the elderly (205). It is defined as a skeletal disorder characterized by compromised bone strength predisposing a person to an increased risk of fracture (1). Bone strength primarily reflects the integration of bone density and bone quality. Bone density is expressed as grams of mineral per area or volume, and in any given individual is determined by peak bone mass and amount of bone loss. Bone quality refers to architecture, turnover, damage accumulation (i.e., microfractures), and mineralization (1). Trabecular bone is more affected by osteoporosis than cortical bone because it has greater surface area.

The operational definitions of osteoporosis relate to areal BMD measured by DXA (206). As described previously (Section 2.3.1), DXA analyses the amount of mineralized tissue within an aerial section of the spine or the proximal femur and expresses bone mass in grams per $cm^2$. Severe osteoporosis is defined as areal BMD at least 2.5 standard deviations below the adult peak mean together with evidence of low-trauma fractures (i.e., fragility fractures). Osteoporosis is areal BMD at least 2.5 standard deviations below adult peak mean without evidence of low-trauma fractures. Osteopenia is areal BMD between 1 and 2.5 standard deviations below adult peak mean without evidence of low-trauma fractures. An individual whose areal BMD is better than 1 standard deviation below the young adult mean is considered normal.

Osteoporosis can be further characterized as either primary or secondary (1). Primary osteoporosis can occur in both sexes at all ages, but often follows menopause in women and occurs later in life in men. It has no obvious etiological agent. In contrast, secondary osteoporosis is the result of medications (e.g., glucocorticoids) or medical conditions (e.g., hypogonadism, celiac disease, and hypothyroidism).

## 2.4.1.2 Epidemiology of Osteoporosis

The incidence and prevalence of osteoporosis increase with age. By ages 60 to 70 years, of every 9 women in the United States, only one have "normal" BMD, five have osteopenia, and three have osteoporosis (205). After age 80 years, about 70% of women have osteoporosis (206-208).

## 2.4.1.3 Pathogenesis

Despite being the subject of intense study for several decades, the precise pathogenesis of osteoporosis is still not well understood (209). There are, however, three widely accepted fundamental pathogenetic mechanisms of osteoporosis:

1. Failure to achieve optimal peak bone mass during skeletal growth.

2. Excessive resorption of bone once peak bone mass has been achieved.

3. Impaired bone formation response during remodelling.

Adolescence is a period of rapid skeletal growth during which nearly half of the adult skeletal mass is accrued. This stage of life is the window of opportunity for influencing peak bone mass and reducing the risk of osteoporosis later in life. Peak bone mass, which occurs at the conclusion of growth, may be the most important factor in preventing osteoporosis since as much as bone is accrued during the adolescent years as most individuals will lose during all of adult life (210,211). Thus, persons with the highest peak bone mass after adolescence have the greatest protective advantage when bone density declines as a results of aging, illness, and diminished sex-steroid production. Three modifiable factors must be adequate to achieve peak bone mass. They are: dietary calcium intake, mechanical loading, and hormone status.

Calcium is the most abundant mineral in the human body. Approximately 99% of the total calcium stores are contained in the skeleton. Dietary calcium requirements for skeletal maintenance fluctuate throughout a women's life. Calcium requirements are high during adolescence (1300 mg/day) due to the demands of a rapidly growing skeleton. However, it is estimated that only about 25% of boys and 10% of girls aged 9 to 17 years meet these recommendations (1). Low calcium intake during this time may impede reaching peak bone mass. A retrospective study of adult women indicated a positive association between

milk and diary products consumed during adolescence and current areal bone mineral density (212). A 36-month randomized controlled trial reported that a calcium supplementation of 700 mg/day, given above a mean daily calcium intake of about 950 mg, in one member of pairs of identical twins, significantly enhanced the rate of areal BMD gain in prepubertal children (213). Another randomized controlled trial reported a significant increase in spinal areal BMD of 2.9% after 18 months of calcium supplementation (300 mg above a spontaneous intake of about 1000 mg) in pubertal girls (214).

It should be noted that vitamin D is required for optimal calcium absorption. During adolescence, when consumption of dairy products decreases, vitamin D intake is less likely to be adequate, and this may adversely affect calcium absorption (1). However, active children and adolescents normally have sufficient sun exposure to maintain adequate vitamin D levels. The importance of vitamin D in older people is discussed in Sections 2.4.1.4 and 2.4.1.5.

Physical activity during childhood is an important determinant of peak bone mass. Animal studies provide evidence that growing bone has a greater capacity to add new bone to the skeleton than does adult bone (149,153,154,158). The most recent longitudinal observational study of physical activity and bone accural in children demonstrated that active children (with scores in the highest quartile on the Physical Activity Questionnaire for Older Children) not only had significantly higher absolute values for bone mineral one year after peak accumulation, but also had significantly peak bone mineral accrual velocities than inactive children (215). There is also evidence to suggest that there exists a critical period for bone response to exercise during the growing years (216).

Sex steroids secreted during puberty substantially increase BMD and peak bone mass. In adolescents and young women, sustained production of estrogens is essential for the maintenance of bone mass. Thus, those with delayed menarche and menstrual dysfunction (i.e., amenorrhea and oligomenorrhea) are at risk of not achieving peak bone mass and premature bone loss (1). Estrogens are also vital in the growth and maturation of the male skeleton (1). The male sex hormone testosterone production is similarly important in adolescent boys and men to achieve and maintain maximal bone mass.

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Women have an abrupt drop in bone mass occurring around menopause as estrogen deficiency results in increased bone turnover and net bone loss (217). High bone turnover is a risk factor for fracture independent of bone density in older adults (218,219). Specifically, vertebral fracture rate per 1000 person years was shown to increase at both low BMD ( < 0.8 g/cm2) and at a high bone formation rates ( > 4.0% per year) (219). It is thought that the microcracks associated with increased remodelling may be weak points that permit fracture. Aging is probably a critical factor in the impairment of bone formation (220). Although the precise pathogenetic mechanisms remain unknown, a number of risk factors for osteoporosis have been identified.

## 2.4.1.4 Risk Factors

Key factors that have been identified in the development of osteoporosis are: genetics, estrogen and other systemic hormones, age, sex, diet, lifestyle factors, physical activity, and medications.

The greatest influence on a woman's peak bone mass is heredity. Studies have suggested that up to 80% of the variability in peak bone mass might be attributable to genetic factors (221,222). The risk of osteoporosis is increased in individuals with a positive family history of fragility fractures (223). Also, first degree relatives of individuals with vertebral fractures have lower bone mass (224). There have been many studies examining polymorphisms in candidate genes that might account for these effects. The initial polymorphism identified was in the vitamin D receptor (225). As it is likely that osteoporosis is a polygenic disorder with different patterns in different groups of individuals, the candidate gene approach to research in this field may not be optimal (209).

Many studies have demonstrated that estrogen deficiency accelerates bone loss (226,227). This rapid loss, approximately 2 to 4% per year, appears to subside gradually within 5 to 10 years in the absence of treatment (205). However, the precise mechanisms by which estrogen deficiency results in bone loss have not been identified. Estrogen receptors have been identified in osteoblasts, osteoclasts, and osteocytes as well as in the hematopoietic and vascular cells adjacent to bone (209). While there is substantial evidence that estrogen is anti-resorptive, the mechanism of these effects appears to be quite

complex (209). Estrogen can inhibit bone resorption by shortening the life span of osteoclasts (by promoting apoptosis) and by altering the production of local factors that regulate osteoclast formation (228). Estrogen may also alter the production of, or response to, systemic hormones, such as parathyroid hormone (PTH) and vitamin D, or cytokines and other local factors that influence bone resorption. Overall, women lose about one-third of their BMD between menopause and age 80 (229).

Other systemic hormones, such as parathyroid hormone, testosterone, progesterone, and the growth hormone (GH)/insulin-like growth factor (IGF) system, are also implicated in postmenopausal bone loss and in age-related bone loss in both sexes (209). A pathogenic role for parathyroid hormone in age-related bone loss is supported by many studies (230). Decreases in calcium ion concentration in the extracellular fluid cause the parathyroid glands to increase their rate of secretion (231). PTH causes proliferation of osteoclasts and subsequent increases in osteoclast activity. Estrogen deficiency may also increase PTH levels. Excess PTH is associated with cortical bone loss due to increased endosteal and intracortical resorption (209). However, PTH can stimulate bone formation as well as bone resorption as intermittent PTH is an effective anabolic agent (232). Testosterone may play a role in postmenopausal osteoporosis as its production was decreased in women with vertebral fractures (233). Although progesterone has been shown to stimulate bone growth in fetal tissues, whether or not it has a direct effect on bone in humans remains controversial (209,234). The effects of hormone replacement therapy on the skeleton are the same whether estrogen is administered with or without progesterone. Growth hormone and IGF-1, which are maximally secreted during puberty, continue to play a role in the acquisition and maintenance of bone mass into adulthood (235). Growth hormone strongly stimulates the osteoblasts. The average plasma concentration of growth hormone decreases with age (231). IGF-1 is a potent stimulator of osteoblast replication and matrix synthesis (209). Associations between osteoporosis and low IGF-1 have been reported in men with osteoporosis (236).

Superimposed on the bone loss induced by estrogen deficiency is a gradual loss of bone often referred to as age-related loss, which persists indefinitely. Women who are more than 5 years

postmenopausal lose bone at about 1 to 2% per year, which is about twice the rate for men of similar age (205).

Adequate dietary levels of calcium and vitamin D are associated with slower rates of bone loss (237,238). Vitamin D is not a normal constituent of most foods but is typically produced endogenously by a cutaneous photosynthetic reaction (239). Severe deficiency of vitamin D leads to impaired mineralization and osteomalacia, but moderate deficiencies are associated with osteoporosis. Deficiency in vitamin D is quite common in older people, particularly in latitudes where there is insufficient sunlight to stimulate adequate vitamin D production in the skin during the winter months (209). There is a high prevalence of vitamin D insufficiency, defined as 25-hydroxyvitamin D less than 40 nmol/L among a community-dwelling population (N = 188) of healthy Canadians living in Calgary (latitude 51 degrees north) (240). There was a decrease in areal BMD of the spine between January and June in healthy postmenopausal women living in northeastern United States (latitude 42 degrees) (237).

Dietary calcium requirements increase at menopause due to a decrease in the efficiency of utilization, which is associated with the fall in ovarian estrogen production (241). In addition, by age 65, intestinal calcium absorption has typically declined to less than 50% of that in adolescents (242). One factor that may limit calcium absorption is a lack of vitamin D, resulting from age-related declines in several functions, including ingestion, dermal synthesis, renal enzymatic activity, and intestinal responsiveness (229). Vitamin D is hydroxylated in the kidney to calcitriol (239). Calcitriol influences calcium absorption by binding to a mucosal nuclear receptor and inducing the synthesis of a calcium-binding transport protein needed for active calcium absorption across the intestinal mucosal barrier.

Certain lifestyle factors, such as smoking, caffeine consumption, and alcohol, are associated with low bone density (205,243,244). High caffeine consumption may contribute to bone loss because of increased urinary calcium losses (243). Alcohol abuse is a strong risk factor for bone loss (245) but studies of *moderate* alcohol intake have been inconsistent (244,246). Moderate alcohol consumption in women 65 years of age and older seems to increase areal BMD (247) and lower the risk of hip fracture (246).

Muscle forces cause the largest voluntary bone loads and strains and strongly influences bone strength and mass (muscle-bone unit) (248). This is one mechanism whereby physical activity throughout the life span may promote and maintain bone health. To move us around, muscles must fight the resistance of the body's weight multiplied by the bad lever arms most muscles work against (249). During growth, modeling adapts bone strength to mechanical loads to prevent them from breaking bones. Since it takes stronger muscles to move heavier bodies around, bone mass should correlate well with body weight in normally active individuals, as it does (250). Thus, voluntary muscle forces should dominate a bone's postnatal structural adaptations to its mechanical usage, modified by body weight and one's voluntary physical activities (250).

Use of high-dose glucocorticoid is associated with accelerated bone loss (205) and is the most common cause of drug-related (secondary) osteoporosis. The long-term administration of glucocorticoids for conditions such as rheumatoid arthritis and chronic obstructive pulmonary disease is associated with a high rate of fracture (1). Other medications suspected of contributing to bone loss (secondary osteoporosis) include heparin, anticonvulsants as well as excess or insufficient thyroid hormone (205).

2.4.1.5 Therapy

Drugs for treating osteoporosis may be divided into those that suppress bone resorption and those that stimulate bone formation (251). The former include agents such as estrogens, bisphosphonates, calcium, and vitamin D supplements. The latter include agents such as sodium fluoride, anabolic steroids, growth hormone, growth factors, and more recently, PTH. As the current mainstay of therapy for osteoporosis is anti-resorptive in mechanism, bone forming agents are not discussed in this thesis.

Agents that decrease bone resorption may either block bone resorption directly or indirectly by suppressing PTH secretion (251). Bisphosphonates are potent inhibitors of osteoclastic bone resorption. A systematic review and meta-analysis indicate that cyclic etidronate, alendronate, and risedronate increase areal BMD at the lumbar spine and proximal femur in a dose-dependent manner (1). The increase in bone density with bisphosphonates is variable depending on the site and the drug but is generally less than 10%

over 3 years (252). Bisphosphonates reduce fractures at the spine, and both alendronate and risedronate reduce hip fracture rates as well (251).

The effects of weight-bearing jumping exercise and oral alendronate on the mass and structure of bone were evaluated in a 12-month randomized, double-blind, placebo-controlled trial utilizing a full factorial design (194). A total of 164 healthy, sedentary, early postmenopausal (i.e., 1-5 years postmenopausal) women were randomized to one of four experimental groups: 1) 5mg/d alendronate, 2) 5 mg/d alendronate plus progressive jumping exercise, 3) placebo plus progressive jumping exercise, and 4) placebo. Bone outcome measures included both DXA and pQCT. Alendronate was effective in increasing bone mass (BMC by DXA) at the lumbar spine (alendronate vs. placebo 3.5%, 95% CI 2.2 to 4.9) and femoral neck (1.3%, 95% CI 0.2 to 2.4%). Exercise alone had no effect on DXA-derived BMC at the lumbar spine or femoral neck. It had neither an additive effect nor an interaction effect with alendronate at these bone sites. However, exercise significantly increased both density-weighted polar section modulus (SSI; 3.6%, 95% CI 0.3 to 7.1) and the ratio of cortical bone to total bone area (3.7%, 95% CI 0.1 to 7.3) in the distal tibia. Bone turnover was reduced by alendronate only. Based on these results, alendronate is effective in increasing bone mass at the lumbar spine and femoral neck, while exercise is effective in increasing the mechanical properties of bone. An earlier study also found no additive effect between resistance training and the less powerful bisphosphonates, etidronate, in postmenopausal women on bone mass as measured by DXA (253).

Both calcium and vitamin D supplements decrease bone resorption by suppressing the secretion of PTH. Chapuy et al. (254) examined the effects of vitamin D and calcium supplementation on the frequency of nonvertebral fractures in 3270 healthy ambulatory women (mean age = 84, SD = 6) living in 180 nursing homes for 18 months. At the completion of the study, the number of hip fractures was 43% lower and the total number of nonvertebral fractures was 32% lower among those receiving active supplementation than those receiving placebo. Furthermore, in a three year prospective study involving both men and women 65

years or older, it was shown that dietary supplementation with calcium and vitamin D reduced bone loss at the femoral neck, spine, and total body and also reduced the incidence of nonvertebral fractures (255).

There is evidence to suggest that vitamin D may reduce the incidence of fractures by maintaining neuromuscular function (256) and thus, it is postulated that the benefit of vitamin D supplementation in fracture prevention may be partly mediated through a reduction in falls (257). However, a recent systematic review concluded there is insufficient evidence that vitamin D supplementation alone improves physical performance in older people (105) and that future large, well-designed trials are needed to confirm the benefits of vitamin D combined with calcium supplementation on physical performance.

As discussed previously in Section 2.4.1.4, the working mechanism of estrogen is not completely understood. Evidence from both animal (258,259) and human studies (260) suggest that estrogen replacement therapy and exercise have an additive effect on the postmenopausal skeleton. In 62 older women between the ages of 60 to 72 years, hormone replacement therapy (conjugated estrogens 0.625 mg/day and tri-monthly medroxyprogesterone acetate 5mg/day for 13 days) was shown to augment bone mineral by reducing the rate of resorption and, to a lesser degree, the rate of formation, whereas exercise had no effect on formation and reduced resorption by a different mechanism (260). However, the use of estrogen (replacement therapy) as a mean of preventing and treating osteoporosis came into question after the July 2002 report of the Women's Health Initiative (261). The Women's Health Initiative, a US National Institutes of Health program, is the first study to compare hormone replacement therapy to placebo in healthy women. This study was terminated early due to its findings of increased cardiovascular events and breast cancer diagnosis in women on hormone replacement therapy.

Anti-resorptive agents lead to a decrease in bone turnover, because bone resorption initiates bone formation in the remodelling cycle. Both the birth rate of new remodelling units and remodelling space decrease as a result of these bone resorption suppressing agents (251). This results in an initial increase in bone mass secondary to the bone remodelling transient (118), which is a temporary dissociation

between bone resorption and bone formation rates. The subsequent increase in bone mass observed with bisphosphonates is due to further mineralization of bone tissue (262).

### 2.4.2 Exercise: Its Role in Promoting Bone Health in Postmenopausal Women

This thesis focuses on physical activity in older people with low bone mass. Therefore, in this section, I detail the relevant studies, both animal and human, of physical activity on bone health.

2.4.2.1 Animal Models

The ovariectomized (OVX) rat is the most often used animal model of postmenopausal bone loss. Ovariectomy-induced bone loss in the rat and postmenopausal bone loss (in humans) have many similar characteristics, such as: increased rate of bone turnover with resorption exceeding formation; an initial rapid phase of bone loss followed by a much slower phase, greater loss of cancellous than cortical bone; decreased intestinal absorption of calcium; and similar skeletal response to therapy with estrogen, tamoxifen, bisphosphonates, parathyroid hormone, calcitonin, and exercise (263).

Results from studies using the ovariectomized rat model of postmenopausal bone loss suggest that exercise or mechanical loading can successfully prevent estrogen-deficiency-induced bone loss in ovariectomized animals. Exercise has been associated with increased bone mineral mass (264), improved architecture (265), and mechanical strength (266) in ovariectomized rats. For example, 18 weeks of exercise (running program) prevented the decrease in bone strength (induced by ovariectomy) of the femoral neck, tibia, and humerus in 12-week old exercising OVX rats (266). However, one should note that 12-week old rats are still growing (263), and thus, may not provide an ideal model of bone loss associated with the aging postmenopausal skeleton.

As well as preventing bone loss, evidence from animal studies suggests that mechanical loading may actually reverse bone deficits induced by estrogen deficiency. Notomi et al. (267) recently demonstrated in their two-part experiment that tower-climbing exercise had both a preventive and recovery effect on bone strength in ovariectomized rats. In part one of the experiment, 60 12-month old rats were assigned to four groups: baseline control, sham-operated sedentary, OVX-sedentary, and OVX-exercise.

Exercise started three days after ovariectomy. For exercise, the OVX-exercise rats climbed a 200-cm tower to drink water. At three months, the OVX-sedentary group had elevated femoral cortex and lumbar trabecular turnover, leading to a reduction in bone mass and strength. However, in the OVX-exercise groups, bone turnover was maintained at the same level as the sham-operated sedentary rats. Thus, exercise prevented OVX-induced cortical and trabecular bone loss by maintaining bone turnover in the normal range. In part two of the study, 90 15-month old rats started exercise three months after ovariectomy. At three months, OVX resulted in decreased compressive strength of the lumbar vertebral body (L5) compared with sham-operated. In addition, the total cross-sectional area (CSA), cortical bone area, moment of inertia, and bending load values had decreased in the midfemur. However, at six months after ovariectomy (i.e., after three months of exercise training), the parameters of breaking load in both the lumbar (compressive strength) and midfemur (three-point bending), lumbar bone mass, and the total CSA recovered to the same level in the OVX-exercise rats as those in the sham-operated sedentary rats. However, the cortical bone area of the midfemur did not recover. The improvement in cross-sectional morphology without an increase in cortical bone area suggest cortical drift (i.e., periosteal expansion with endosteal resorption) which is associated with mechanical stimulation (267).

Histomorphometric data from studies of ovariectomized rats suggest that exercise minimizes bone loss induced by estrogen deficiency by decreasing bone resorption (258,259,265). For example, mechanical loading by ambulation prevented trabecular bone loss in OVX rats by inhibiting bone resorption (265). Also, four months of treadmill exercise decreased osteoclast perimeter without a significant effect on osteoblast number or bone incorporation of $^{45}$calcium in 12 month-old OVX rats' tibia (ovariectomized at 10 months of age) (258). Furthermore, histomorphometric data have shown exercise to decrease the periosteal bone formation rate and mineral apposition rate at the femoral shaft, but increased it at the endosteum in 12-week old OVX rats (266). However, histomorphometric data also show that exercise stimulated periosteal apposition in the tibial shaft of 37-week OVX rats (264). These inconsistencies between study results (264,266,267) are likely due to differences in methodology, such as the age of the

rats (15-month old versus 12-week old). Although the mechanism for augmenting bone health may differ among various experimental models, the findings are in agreement with Frost's mechanostat theory (125) of mechanical loading and adaptation responses of bone -- increased mechanical loading stimulates bone formation and depresses bone resorption.

2.4.2.2 Studies In Postmenopausal Women

There are several inconsistencies among studies of the effect of exercise on bone health in postmenopausal women. For example, although walking increased areal BMD of the lumbar spine in a 7-month trial (268), it had no effect in two trials of greater duration (269,270). As well, some researchers have reported a positive effect of resistance training at the proximal femur (12,62) while others found no change (271). The inconsistencies in the results may be due to the following factors:

1. Different study designs: It is impossible to compare results between cross-sectional, longitudinal observational, randomized, and non-randomized intervention study designs.

2. Different cohorts: It is difficult to compare results between studies using cohorts of different age, physical activity level, and health status.

3. Different types of exercise intervention programs: It is difficult to compare results between exercise of different types, intensities, frequencies, and durations.

4. Technology: The majority of intervention studies to date used DXA-derived outcome measures. However, as mentioned earlier in Section 2.3.1.2, DXA may seriously underestimate the effects of mechanical loading on bone secondary to its inherent planar nature.

Thus, this literature review focuses on randomized controlled trials of exercise intervention in postmenopausal women and Table 6 summarizes these studies. I searched MEDLINE database, covering 1966 to present, with the following key words: exercise, postmenopausal, aged, and bone density. This search was limited to English language publications and randomized controlled trials. I also cross-checked references from these papers and all those in my collection to try to include all relevant papers.

Table 6. Randomized controlled trials of exercise intervention in postmenopausal women on bone.  Studies are listed in chronological order (with the most recent one listed first).

| First Author & Date | Participants | Exercise Intervention | Outcome Measure & Results* |
|---|---|---|---|
| Uusi-Rasi, 2003 (194) | 164 sedentary early postmenopausal women (mean age = 53.4). | Four experimental groups (factorial design): 1) alendronate (5mg/d), 2) alendronate & exercise, 3) exercise, and 4) control.  Exercise entailed of multidirectional jumping; progressive in nature (10 to 25cm). <br> Duration:  12 months <br> Frequency:  3x/week, 60 minutes/session | pQCT: <br> 1) Distal tibia. <br> 2) Midshaft tibia. <br><br> DXA: <br> 1) Lumbar spine BMC. <br> 2) Femoral neck BMC. <br> 3) Trochanter BMC. <br> 4) Distal radius BMC. <br><br> Results:  Exercise significantly increased (1.0%) distal tibia pQCT-derived BMC.  Exercise also significantly increased (3.6%) polar SSI and the (3.7%) ratio of cortical to total area. <br> No significant differences between the exercise and the control groups in DXA measures. |
| Iwamoto, 2001 (272) | 35 women with osteoporosis (receiving calcium and vitamin D supplementation) between 53 to 77 years of age.  Mean age of exercisers = 65.3, SD = 4.7, of detrainers = 64.3, SD = 3.0, and of controls = 64.9, SD = 5.7. | Three experimental groups:  1) brisk walking & gymnastic training for two years, 2) brisk walking & gymnastic training for one year followed by one year of detraining, and 3) control. <br> Duration:  2 years <br> Frequency:  daily <br> Intensity:  increase daily step count by 30% | Lumbar spine BMD measured by DXA after year 1 and year 2. <br><br> Results:  2-year exercisers significantly increased lumbar spine BMD compared with controls after year 1 and year 2.  Detrainers significantly increased lumbar spine BMD compared with controls after year 1 but not after year 2 detraining year. <br> LS:  3.33 for 2 year training; 1.23 for 1 year |

| First Author & Date | Participants | Exercise Intervention | Outcome Measure & Results* |
|---|---|---|---|
| Adami, 1999 (13) | 250 women between 52 to 72 years of age. Mean age of exercisers = 65, SD = 6 and of controls = 63, SD = 7. | Two experimental groups: exercise and control. Exercises designed to maximize the stress on the wrist. Duration: 6 months Frequency: 2x/week, 70 minutes/session; participants also encouraged to repeat all exercises at home for at least 30 minutes/day | training and 1 year detraining. pQCT: 1) Ultradistal radius. 2) Proximal radius. DXA: 1) Lumbar spine BMD. 2) Femoral neck BMD. 3) Ward's triangle BMD. 4) Trochanter BMD. 5) Ultradistal radius BMD. 6) Proximal radius BMD. Results: No significant differences between the groups for any pQCT measures of the proximal radius. Significant differences between groups for cortical area, cortical BMC, and trabecular BMC at the ultradistal radius. 1) Cortical area: 3.0 2) Cortical BMC: 3.3 3) Trabecular BMC: -3.8 No significant differences between the groups for any DXA measures. 1) LS: 0.5 2) FN: -0.1 3) TR: -0.4 4) WT: 1.6 5) UDR: 0.2 6) PR: -0.4 |
| Ebrahim, 1997 | 165 women with a previous history of | Two experimental groups: self-paced brisk | DXA: |

| First Author & Date | Participants | Exercise Intervention | Outcome Measure & Results* |
|---|---|---|---|
| (270) | fracture in the upper limb. Mean age of exercisers = 66.4, SD = 7.8 and of controls = 68.1, SD = 7.8. | walking and control (upper extremity exercises). Duration: 24 months Frequency: daily, up to 40 minutes/session | 1) Lumbar spine BMD. 2) Femoral neck BMD. Results: No significant differences between the groups. Femoral neck BMD had decreased in the controls to a greater extent than in the exercisers. 1) LS: –0.1 2) FN: 2.4 |
| McMurdo, 1997 (273) | 118 women between 60 to 73 years of age (mean age = 64.5). | Two experimental groups: calcium supplementation and exercise & calcium. Exercise was weight-bearing exercise to music. Duration: 12 months Frequency: 3x/week, 45 minutes/session | BMC of non-dominant forearm by SPA. BMD of lumbar spine by QCT. Results: Significant difference between groups in UDF. No significant difference between groups in lumbar spine. UDF: 3.7 LS: 1.7 |
| Bravo, 1996 (71) | 124 women between 50 to 70 years of age with low bone mass, defined as spinal BMD less than 1 g/cm or proximal femur BMD less than 0.9 g/cm. Mean age of exercisers = 59.6, SD = 5.82 and of controls = 59.9, SD = 6.36. | Two experimental groups: exercise (weight-bearing exercises, aerobics, resistance and flexibility exercises) and control. Duration: 12 months Frequency: 3x/week, 60 minutes/session Intensity: aerobics = 60 to 70% of heart rate reserve; resistance = 1 set of 12 to 15RM | DXA: 1) Lumbar spine BMD. 2) Femoral neck BMD. Results: Lumbar spine BMD stabilized in the exercisers while decreased significantly in the controls. No significant change in femoral neck in either group. 1) LS: 1.8 2) FN: 0.8 |
| Kerr, 1996 (12) | 56 women between 40 and 70 years of age. Mean age of endurance group = 55.7, SD = 4.7 and of resistance group = 58.4, SD = 3.7. | Two experimental groups: resistance training group (RT) and endurance (ET) group. Contralateral side acted as nonexercising control. | DXA measured every 3 months: 1) Trochanter BMD. 2) Intertrochanter BMD. 3) Femoral neck BMD. |

| First Author & Date | Participants | Exercise Intervention | Outcome Measure & Results* |
|---|---|---|---|
| | | Duration: 12 months<br>Frequency: 3x/week<br>Intensity: resistance = 3 sets of 8RM;<br>endurance = 3 sets of 20RM for endurance training | 4) Ward's triangle BMD.<br>5) Ultradistal radius BMD.<br>6) Mid radius BMD.<br>7) 1/3 radius BMD.<br><br>Results: Significant increase in bone mass at trochanter, intertrochanter, Ward's triangle, and ultradistal radius with RT compared with control. Significant increase at mid radius with ET.<br>1) TR: 2.3 RT; -0.9 ET<br>2) IT: 1.6 RT; -0.2 ET<br>3) FN: 0.4 RT; 1.2 ET<br>4) WT: 1.5 RT; 1.0 ET<br>5) UDR: 3.6 RT; 0.1 ET<br>6) MR: 1.2 RT; 1.1 ET<br>7) 1/3 R: 1.1 RT; 1.0 ET |
| Lord, 1996 (69) | 179 women between 60 to 85 years of age (mean age = 71.6, SD = 5.3). | Two experimental groups: exercise (resistance, coordination, and balance exercises) and control.<br>Duration: 12 months<br>Frequency: 2x/week, 35 minutes of weight-bearing/session | DXA:<br>1) Lumbar spine BMD.<br>2) Femoral neck BMD.<br>3) Trochanter BMD.<br><br>Results: No significant differences between the groups.<br>1) LS: 0.7<br>2) FN: -1.6<br>3) TR: 0.0 |
| Bassey, 1995 (274) | 44 women between 50 to 60 years of age. Mean age of exercisers = 54.0, SD = 4 and of controls = 55.0, SD = 3.0. | Two experimental groups: exercise and control. Exercisers performed 50 "heel drops" daily at home and had a weekly exercise class that included high impact activity. Flexibility and | DXA measured at 6 and 12 months:<br>1) Ultradistal forearm BMD.<br>2) Lumbar spine BMD.<br>3) Femoral neck BMD. |

| First Author & Date | Participants | Exercise Intervention | Outcome Measure & Results* |
|---|---|---|---|
| | | low-impact exercises for controls.<br>Duration: 12 months<br>Frequency: "heel drops" daily, up to 50 repetitions | 4) Ward's triangle BMD.<br>5) Trochanter BMD.<br><br>Results: No significant differences between the groups with respect to any change.<br>1) UDF: 1.6<br>2) LS: 2.2<br>3) FN: -0.8<br>4) WT: -1.0<br>5) TR: 1.4 |
| Prince, 1995 (275) | 168 women who were more than 10 years postmenopausal (mean age = 63). | Four experimental groups: 1) placebo, 2) milk powder, 3) calcium, and 4) calcium & exercise. Exercisers aimed to undertake 2 extra hours of weight-bearing per week and 2 extra hours of walking.<br>Duration: 24 months<br>Intensity: 60% of peak heart rate while walking | DXA every 6 months:<br>1) Lumbar spine BMD.<br>2) Femoral neck BMD.<br>3) Intertrochanter BMD.<br>4) Trochanter BMD.<br>5) Ultradistal ankle BMD.<br><br>Results: Calcium & exercise had less bone loss at the FN (0.95) compared with calcium alone. |
| Pruitt, 1995 (276) | 26 Caucasian women between 65-79 years of age (mean age = 68). | Three experimental groups: 1) high-intensity resistance training, 2) low intensity resistance training, and 3) control. Ten exercises.<br>Duration: 12 months<br>Frequency: 3x/week<br>Intensity: high-intensity = 80% of 1RM; low intensity = 40% of 1RM. Low intensity performed twice the repetitions as high-intensity. | DXA:<br>1) Lumbar spine.<br>2) Total hip.<br><br>Results: No significant differences among the groups:<br>1) LS: 0.8<br>2) TH: -0.1 |
| Nelson, 1994 (62) | 40 Caucasian women between 50 to 70 years of age. Mean age of exercisers = | Two experimental groups: high-intensity resistance training and control. | DXA:<br>1) Whole body BMD. |

| First Author & Date | Participants | Exercise Intervention | Outcome Measure & Results* |
|---|---|---|---|
| | 57.3 and of controls = 61.1. | Duration: 12 months<br>Frequency: 2x/week, 45 minutes/session<br>Intensity: 80% of 1RM, 3 sets of 8 repetitions | 2) Lumbar spine BMD.<br>3) Femoral neck BMD.<br><br>Results: Significant increase in lumbar spine and femoral neck BMD with resistance training compared with the control group.<br>1) WB: 3.2<br>2) LS: 2.8<br>3) FN: 3.4 |
| Hatori, 1993 (268) | 33 women between 45 to 67 years of age. Mean age of moderate intensity exercisers = 58, SD = 5, of high-intensity exercisers = 56, SD = 4, and of controls = 58, SD = 8. | Three experimental groups: 1) moderate intensity, 2) high-intensity, and 3) control. Exercisers walked on flat ground at exercise intensity.<br>Duration: 7 months<br>Frequency: 3x/week, 30 minutes/session<br>Intensity: moderate intensity = 90% of the heart rate at anaerobic threshold; high-intensity = 110% of the heart rate at anaerobic threshold | Lumbar spine BMD measured by DXA.<br><br>Results: Significant increase in lumbar spine BMD with high-intensity exercise compared with the control group.<br>LS: 1.2 for moderate intensity; 4.8 for high-intensity. |
| Martin, 1993 (269) | 76 women at least 12 months postmenopausal. Mean age of 30 minute exercisers = 60.3, SD = 7.8, of 45 minute exercisers = 57.8, SD = 7.1, and of controls = 56.7, SD = 6.9. | Three experimental groups: 1) treadmill walking for 30 minutes, 2) treadmill walking for 45 minutes, and 3) control.<br>Duration: 12 months<br>Frequency: 3x/week<br>Intensity: 70 to 85% of maximum heart rate | Lumbar spine BMD by DPA.<br><br>Results: No significant differences among the groups.<br>LS: 0.13 for 30 minutes; 1.42 for 45 minutes. |
| Revel, 1993 (277) | 89 Caucasian women (mean age = 54, SD = 3). | Two experimental groups: psoas muscle training and deltoid muscle training (control).<br>Duration: 12 months<br>Frequency: daily, 60 repetitions of hip flexions | Lumbar spine BMD by QCT.<br><br>Results: No significant differences among the groups although greater bone loss in controls than psoas muscle training group.<br>LS: 2.3 |
| Grove, 1992 | 15 women. Mean age of low impact | Three experimental groups: 1) low impact | Lumbar BMD using DPA. |

| First Author & Date | Participants | Exercise Intervention | Outcome Measure & Results* |
|---|---|---|---|
| (278) | execisers = 56.6, of high impact exercisers = 54.0, and of controls = 56.0. | exercise, 2) high impact exercise (peak forces 2x body mass), and 3) control.<br>Duration: 12 months<br>Frequency: 3x/week, 20 minutes/session | Results: No significant differences between the two exercise groups. Exercisers maintained BMD during the study. Controls demonstrated a significant linear decrease in BMD.<br>LS: 7.8 for high impact; 6.09 for low impact. |
| Lau, 1992 (279) | 50 Chinese women between 62 to 92 years of age (mean age = 76). | Four experimental groups (factorial design): 1) calcium supplement, 2) exercise & placebo, 3) calcium & exercise, and 4) placebo. Exercise entailed stepping up and down a 23 cm block 100 times and 15 minutes of upper trunk exercises.<br>Duration: 10 months<br>Frequency: 4x/week | DXA:<br>1) Lumbar spine BMD.<br>2) Femoral neck BMD.<br>3) Ward's triangle BMD.<br>4) Trochanter BMD.<br><br>Results: Exercise had no effect on bone loss at any site. However, there was a joint effect of calcium and exercise at the femoral neck.<br>1) LS†: 0.6<br>2) FN: -5.5<br>3) WT: -3.6<br>4) TR: -0.1 |
| Notelovitz, 1991 (280) | 20 surgically menopausal women. Mean age of estrogen group = 46.2, SD = 6.8 and of estrogen & exercise = 43.3, SD = 9. | Two experimental groups: estrogen and estrogen & exercise. Exercise entailed a resistance circuit (Nautilus equipment) of 5 basic stations; 1:1 instruction.<br>Duration: 12 months<br>Frequency: 3x/week, 15 to 20 minutes/session<br>Intensity: 1 set of 8RM | DPA:<br>1) Spine BMD.<br>2) Total body BMD.<br>3) Midshaft radius BMD.<br><br>Results: No significant differences between the groups in spine or total body BMD. Significant increase in midshaft radius BMD with estrogen and exercise compared with estrogen alone.<br>1) S: 6.8 |

| First Author & Date | Participants | Exercise Intervention | Outcome Measure & Results* |
|---|---|---|---|
| | | | 2) TB: 1.5 <br> 3) MR: 4.4 |
| Sinaki, 1989 (281) | 65 Caucasian women without osteoporosis between 49 to 65 years of age. Mean age of exercisers = 55.6, SD = 4.5 and of controls = 56.5, SD = 4.5. | Two experimental groups: back strengthening exercise (prone lumbar extensions) and control. <br> Duration: 24 months <br> Frequency: 5 days/week <br> Intensity: 30% of the maximal isometric back muscle strength, 10 repetitions | Lumbar spine BMD by DPA every 6 months. <br><br> Results: No significant difference between the two groups. <br> LS: -0.2 |
| Chow, 1987 (282) | 48 Caucasian women between 50 to 62 years of age (mean age = 56). | Three experimental groups: 1) aerobics, 2) aerobics & light resistance training, and 3) control. <br> Duration: 12 months <br> Frequency: 3x/week, 30 minutes/aerobic session, 15 minutes/resistance training session <br> Intensity: aerobics = 80% of the functional maximum heart rate; resistance = 10 reps of 10RM | Bone mass of trunk and upper thigh measured by neutron activation analysis. <br><br> Results: Significant differences between exercisers and controls. <br> Bone mass: 5.3 for aerobics; 9.1 for aerobics and resistance training. |

*Percentage change in bone density in exercise group minus percentage change in bone density in control group. A positive value indicates that participants in the exercise group lost less bone, on average, than those in the control group.

BMD = bone mineral density; DPA = dual photon absorptiometry; DXA = dual energy X-ray absorptiometry; FN = femoral neck; IT = intertrochanter; LS = lumbar spine; MR = midshaft radius; PR = proximal radius; QCT = quantitative computed tomography; RM = repeated maximum; S = spine; TH = total hip; TR = trochanter; WB = whole body; WT = Ward's triangle; UDA = ultradistal ankle; UDF = ultradistal forearm; UDR = ultradistal radius; 1/3 R = 1/3 radius.

†Values indicated are percentage change in exercise only minus change in control only.

Based on the results of these randomized controlled trials, both resistance training and weight-bearing (i.e., impact) exercises of sufficient intensity appear to have beneficial effects on bone health in postmenopausal women. Table 7 summarizes the effect of exercise in postmenopausal women and is adapted from a recent systematic review of prospective randomized controlled trials of the effect of exercise in pre- and postmenopausal women (15). The authors concluded that exercise slows bone loss from the lumbar spine and probably the neck of the femur in postmenopausal women but more research is needed to reach a firm conclusion (15). The authors did not examine the role of exercise on bone structure (as distinct from mass alone) as there are few such studies to date.

Table 7. Pooled measures of effect of exercise on bone mass based on estimated percentage changes in bone density per year (annualized data) and on published data (15).

| Postmenopausal Women | Pooled Measured of Effect (95% CI)* | |
|---|---|---|
| *(Area of Interest, Type of Exercise)* | Annualized Data[†] | Published Data |
| Spine, impact exercise | 1.3% (0.7 to 19%) | 1.6% (1.0 to 2.2%) |
| Spine, non-impact exercise | 1.0% (0.4 to 1.65) | 1.0% (0.4 to 1.6%) |
| Femoral neck, impact exercise | 0.5% (0.1 to 0.9%) | 0.9% (0.5 to 1.3%) |
| Femoral neck, non-impact exercise | 1.4% (0.2 to 2.6%) | 1.4% (0.2 to 2.6%) |

*Percentage differences in change in bone density in exercise group minus percentage change in control group. A positive value indicates that subjects in the exercise group lost less bone, on average, than those in the control groups. CI = confidence interval.
†Study results converted to differences in percentage change in bone density per year. For example, if there was a 1% difference in bone density after a 6-month exercise program, it was assumed by Wallace and Cumming (15) that there would have been a 2% difference if the program had continued for 12 months.

Of the randomized controlled trials reviewed by Wallace and Cumming (15), that by Grove et al. (278) found the largest effect of exercise on the lumbar spine (7.8% bone loss prevented). This is likely secondary to the high compliance achieved with the high-intensity impact (ground reaction force = 2.8 times body mass) exercise program. Nelson et al. (62) found the largest effect (3.4%) at the femoral neck. This is also likely secondary to the high compliance achieved with their high-intensity resistance training regime.

The beneficial effects of exercise on bone health in postmenopausal women, however, do not persist after exercise cessation. For example, Dalsky et al. (283) found a significant decrease in lumbar spine bone mineral content (BMC) after the cessation of an exercise intervention. After both the training and the detraining period (22 months after entering the study), lumbar spine BMC was 1.1% higher than baseline, an insignificant difference.

Current evidence suggests that exercise decreases bone resorption (260,284,285) in postmenopausal women. However, the mechanisms by which exercise promote bone health in this population remain poorly understood. There are very few studies that have assessed biomarkers of both bone formation and resorption, which would better describe the mechanisms by which exercise may augment or maintain bone mass in older postmenopausal women.

In the 2003 Cochrane review of the effectiveness of exercise therapy at preventing bone loss and fractures in postmenopausal women, aerobics, weight bearing, and resistance training exercises all proved effective on augmenting BMD of the lumbar spine (286). The weighted mean difference (i.e., percentage change from baseline) for the combined aerobics and weight-bearing program on the lumbar spine was 1.79 (95% CI 0.58 to 3.01). Walking was shown to be effective on both BMD of the spine (1.31, 95% CI − 0.03 to 2.65) and the hip (0.92, 95% CI 0.21 to 1.64). However, I do note that Hatori et al. (268) found that only high-intensity walking (110% of the heart rate at anaerobic threshold) was effective in increasing lumbar spine areal BMD compared with controls. Furthermore, more studies have examined the effects of exercise on the lumbar spine than on the proximal femur. Thus, more research is needed to delineate the effects of exercise on the proximal femur. Finally, it should also be noted that the reviewers concluded that the quality of the reporting in the meta-analysis was low.

In assessing the effects of exercise on bone health in postmenopausal women, I note that the majority of the published trials to date used DXA measures only, only two studies used other novel outcome measures (13,194). Thus, the possible beneficial effects of exercise on bone's structure are not well-established in this population. Furthermore, although not all exercise programs may have a beneficial

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effect on bone in older individuals, exercise has the potential to reduce fractures via fall risk reduction (e.g., improve muscle strength and postural stability).

To my knowledge, published randomized controlled trials of exercise and bone health have typically targeted women younger than 75 years of age, with one exception (69). This highlights the need for studies in women over that age (75+), as this group has the greatest incidence of both osteoporosis and falls, and thus, fractures.

## 2.5 Exercise Intervention Studies Examining Both Fall Risk and Bone Health

Although it is now well recognized that both increased fall risk and impaired bone health contribute significantly to non-vertebral fractures (9,287), very few published prospective studies have assessed both when determining the role of exercise in fracture prevention in older people (Table 8). Although making important contributions, these previous studies have one or more of the following limitations:

1. With the exception of one study (69), participants were "young" older adults, that is, younger than 70 years of age.

2. With the exception of one study (69), fall risk was assessed using measures that do not have well-established predictive validity or established normative values (e.g., backward tandem walking (62)). A measure of fall risk that has established normative values would allow the comparison of an individual to age-matched counterparts.

3. Where multiple fall risk factors were assessed (e.g., muscle strength and postural stability), there was no a single indicator of overall fall risk (i.e., a composite fall risk score). Providing a composite indicator of fall risk would allow the determination of whether exercise can positively influence the overall fall risk of an individual, rather than just individual fall risk factors.

4. No study compared different dimensions of exercise (i.e., different frequencies, intensity, type, or duration).

5. With the exception of two studies (72,288), these studies did not involve people at particular risk of fractures from falls, such as older individuals with low bone mass.

6. Bone measures were limited to DXA measures. Thus, no indices of bone structure (e.g., cortical wall thickness) or bone strength (e.g., BSI and section modulus) were assessed.

A summary (Table 8) of the few studies that examined the capacity of exercise to ameliorate both fall risk and augment bone health highlights potential novel ways to examine the role of exercise in reducing fracture risk in older adults. Future controlled studies need to incorporate measures of fall risk that are reliable, valid, and have established normative values. State-of-the-art measures of bone health, such as pQCT, are also needed to better assess the full impact of an exercise intervention on the aging skeleton. Furthermore, future studies need to target those at particular risk of sustaining fractures, such as those with low bone mass and those aged 75 years or more.

Table 8. Exercise intervention studies in older adults using outcome measures from the two domains of fracture risk: Fall risk and bone health. Studies are listed in chronological order (with the most recent one listed first).

| First Author & Date | Participants and Design | Exercise Intervention | Results |
|---|---|---|---|
| Uusi-Rasi, 2002 (194) | 164 healthy, sedentary, early postmenopausal women, mean age = 53.4. Four experimental groups (factorial design): 1) alendronate (5mg/d), 2) alendronate & exercise, 3) exercise, and 4) control. Random assignment. | Program: Exercise entailed of multidirectional jumping; progressive in nature (10 to 25cm).<br>Duration: 12 months<br>Frequency: 3x/week | Exercise significantly increased SSI of the distal tibia and the ratio of cortical bone to total bone area compared with no exercise.<br><br>Exercise significantly improved leg extensor power and dynamic balance (figure of eight). |
| Chilibeck, 2002 (253) | 48 postmenopausal women, mean age = 57.4. Four experimental groups (factorial design): 1) etidronate, 2) exercise & etidronate, 3) exercise, and 4) control. Random assignment. | Program: Resistance training using "plate-loaded" equipment.<br>Duration: 12 months<br>Frequency: 3x/week<br>Intensity: stimulus set at 70% 1RM, 1 set of 10 repetitions | Exercise had no effect on any of the DXA measures of the lumbar spine and proximal femur.<br><br>Exercise resulted in significant increases in muscle strength compared with no exercise. |
| Kerschan-Schindl, 2000 (289) | 33 women with a history of postmenopausal fractures and low bone mass; selected retrospectively from a group of 140 women who had been allocated to an exercise group or control group. Mean age of exercisers = 75.1, SD = 5.4, of controls = 69.8, SD = 5.1. | Program: Home exercises aimed at improving posture, coordination (proprioceptive neuromuscular facilitation), and strength (theraband & anti-gravity).<br>Duration: at least 7 years<br>Frequency: advised at least 3x/week | No significant difference between groups in areal BMD of the lumbar spine and proximal femur.<br><br>No significant difference between groups in terms of fracture rates, falls, neuromuscular performance (one leg stance, chair rise, tandem walk, postural stability, and hand tapping). |
| Kronhed, 1998 (288) | 30 community-dwelling women and men between the ages of 40 to 70 years with osteopenia. Two experimental groups: exercise and control. Mean age of exercisers = 55, SD = 11, of controls = 59, SD = 11. Not random assignment. | Program: Balance exercises, back extension exercises, and resistance training.<br>Duration: 12 weeks<br>Frequency: 2x/week | No significant difference between the groups. The exercisers showed significant increase in trochanter areal BMD.<br><br>No significant difference between the groups. Exercisers significantly increased single stance time (eyes closed) while controls did not. |

| First Author & Date | Participants and Design | Exercise Intervention | Results |
|---|---|---|---|
| Bravo, 1997 (72) | 77 community-dwelling women between the ages of 50 to 70 years with low bone mass. No control group. | Program: Water-based exercise program with waist-high water. Duration: 12 months Frequency: 3x/week, 60 minutes/session | Lumbar spine areal BMD decreased significantly whereas there was no change in femoral neck areal BMD. The exercise program significantly improved agility (time to complete agility course) and strength (of the biceps). |
| Lord, 1996 (69) | 179 community-dwelling women between the ages of 60 to 85 years. Mean age of exercisers = 71.7, SD = 5.4, of controls = 71.5, SD = 5.3. Random assignment. | Program: General exercise program incorporated strength and balance exercises. Duration: 12 months Frequency: 2x/week, 60 minutes/session | No significant difference between groups in areal BMD of femoral neck, trochanter, and lumbar spine. The exercise group showed significant improvements in quadriceps strength and postural stability (eyes open on foam). |
| Bravo, 1996 (71) | 124 community-dwelling women between the ages of 50 to 70 years with low bone mass. Mean age of exercisers = 59.6, SD = 5.82, of controls = 59.9, SD = 6.36. Random assignment. | Program: Exercise program incorporated aerobic dancing, weight-bearing exercises, and flexibility exercises. All participants were invited to attend bi-monthly educational seminars. Duration: 12 months Frequency: 3x/week, 60 minutes/session | Lumbar spine areal BMD stabilized in the exercisers while decreased significantly in the controls (significant interaction effect). No change in femoral neck areal BMD was observed in either group. Significant improvement in agility (time to complete agility course) and strength (of the biceps) with exercise. |
| Nelson, 1994 (62) | 40 community-dwelling women between the ages of 50 to 70 years. Mean age of exercisers = 57.3, SD = 6.3, of controls = 61.1, SD = 3.7. Random assignment. | Program: High-intensity resistance training program using 5 different exercises. Duration: 12 months Frequency: 2x/week Intensity: stimulus set at 80% of 1RM, 3 sets of 8 repetitions | Femoral neck areal BMD and lumbar spine areal BMD significantly increased by $0.005 \pm 0.039$ g/cm$^2$ and $0.009 \pm 0.033$ g/cm$^2$ in the exercisers and decreased by $-0.022 \pm 0.035$ g/cm$^2$ and $-0.019 \pm 0.035$ g/cm$^2$, respectively in controls. Exercisers demonstrated significant |

| First Author & Date | Participants and Design | Exercise Intervention | Results |
| --- | --- | --- | --- |
| | | | improvement in strength and balance (tandem backward walking) compared with the controls. |

## Chapter Three:  Rationale, Objectives, and Hypotheses

In this chapter, I outline the rationale, objectives, and hypotheses of the studies that comprise this thesis, followed by the scientific contribution each study makes.

### 3.1 Part One (Chapter Four)

#### *3.1.1 Rationale*

Impaired postural stability and functional mobility are both established fall risk factors (287,290). While there is evidence to suggest that back pain is negatively associated with postural stability (291,292) and functional mobility (293) in healthy people, this relationship has not been examined in individuals with osteoporosis.  Studies (291,292) have demonstrated that adults with chronic low back pain had greater standing postural sway compared with healthy controls.  As increased postural sway has been associated with the propensity to fall (290) and those with osteoporosis are at high risk of sustaining a fracture if they fall, it is important to determine if there is any association between back pain and both postural stability and functional mobility in this population.

#### *3.1.2 Objective*

The objective of this cross-sectional study was to examine the association between back pain and both postural stability and functional mobility in a group of women with osteoporosis aged between of 65 and 75 years.

#### *3.1.3 Hypothesis*

Back pain is negatively associated with postural stability and functional mobility in women with osteoporosis.

#### *3.1.4 Contribution*

This study elucidates the association between back pain and two fall risk factors (postural stability and functional mobility).  The results identify back pain as a potential fracture risk factor in older women with osteoporosis.

## 3.2 Part Two (Chapter Five)

### 3.2.1 Rationale

Fall prevention is well recognized as a vital component of fracture prevention as falls are the primary cause of hip (7) and upper limb fractures (294). A hip fracture is a particularly disabling outcome of falling. About 80 to 90% of hip fractures in older people are secondary to falls (295). A group of individuals at high risk of sustaining fractures with a fall are those with osteoporosis. Whether this population is also at particular risk for falls, however, is not well-established. There is evidence to suggest that older kyphotic women with osteoporosis may have a greater risk of falling compared to their age-matched counterparts without osteoporosis (296). To determine whether fall risk screening is warranted in the medical assessment in older women with osteoporosis requires a comparison of fall risk between those with osteoporosis and healthy age-matched counterparts is needed.

### 3.2.2 Objective

The objective of this cross-sectional study was to compare three established fall risk factors (quadriceps strength, postural stability, and functional mobility) between older women with osteoporosis and age-matched controls without osteoporosis. Previous investigators have identified these three fall risk factors as predictors of hip fractures (7,287) in population-based studies.

### 3.2.3 Hypothesis

Based on the comparison of the fall risk factors (quadriceps strength, postural stability, and functional mobility), older women with osteoporosis are at a greater risk of falling compared to age-matched controls without osteoporosis.

### 3.2.4 Contribution

The results of this study contribute to identifying an association between higher levels of certain fall risk factors and osteoporosis in older women.

### 3.3 Parts Three and Four (Chapters Six and Seven)

#### 3.3.1 Rationale

Approximately 90% of hip fractures are associated with a fall from standing height or lower (7). However, a fall from standing height has enough energy to cause fractures even when bone strength is normal if protective responses are inadequate (e.g., muscle weakness or slowed reaction time) (297,298). Thus, both fall risk and bone health contribute to fracture risk, and exercise has the potential to positively augment both these aspects of fracture risk. However, as mentioned in Section 2.5, very few published controlled exercise studies to date have used both fall risk and bone health as outcome measures. Furthermore, no previous intervention study has used measures of fall risk that have established predictive validity and measures of bone that include its structure.

#### 3.3.2 Objective

The primary objective of this novel randomized controlled trial was to compare the effects of resistance training or agility training on fall risk (as assessed by the PPA), areal BMD (as measured by DXA), and bone structure and strength (as measured by pQCT).

#### 3.3.3 Hypothesis

1) Agility training significantly reduces fall risk score at the end of the 25-week trial compared with resistance training and sham exercise.

2) Agility training will significantly improves the cross-sectional area of the tibial shaft at the end of the 25-week trial compared with resistance training and sham exercise.

#### 3.3.4 Contribution

This study was the first to compare the effects of two different types of exercise programs, high-intensity resistance training and agility training, on the two domains of fracture risk (fall risk and bone health) in a cohort of individuals at high risk of sustaining fall-related fractures (i.e., aged 75 to 85 years with either osteopenia or osteoporosis). Also, this is the only randomized controlled trial to date to use pQCT to compare the effects of *two* different types of exercise programs in individuals with confirmed low

bone mass. Furthermore, to my knowledge, this study provides prospective DXA and pQCT data on the oldest postmenopausal cohort to date (mean age of 79 years). Thus, the results of this study contribute to the understanding of the role of resistance training and agility training in fracture prevention in older women. Also, this study examined the safely and feasibility of these two exercise programs in this high-risk population.

## 3.4 Part Five (Chapter Eight)

### 3.4.1 Rationale

While the fear of falling is a common psychological consequence of falling, older adults who have not fallen also frequently report this fear. Fear of falling can lead to activity restriction that is self-imposed rather than due to physical impairments (299). Thus, fear of falling is an independent contributor of functional decline and consequently, the loss of independence, among older adults (300).

There is some evidence that exercise can significantly improve fall-related self-efficacy, or balance confidence (92,107,301,302). However, it is important that any enhancement of balance confidence is accompanied by an appropriate improvement in physical abilities. To my knowledge, no published prospective reports correlate change in balance confidence, as assessed by a fall-related self-efficacy scale, with change in physical abilities as a result of a group-based exercise program. Furthermore, few data exist on balance confidence in older people with low bone mass.

### 3.4.2 Objective

The primary objective of the study was to examine the relationship between change in balance confidence, as measured by the ABC Scale, and changes in fall risk and physical abilities in older women with low bone mass who underwent 12 weeks of exercise participation. As physical activity curtailment is a common consequence of fear of falling, the secondary objective of this study was to examine the relationship between the change in balance confidence and the change in physical activity level.

### 3.4.3 Hypothesis

Change in balance confidence is correlated with changes in fall risk, physical abilities, and current physical activity level.

### 3.4.4 Contribution

This study contributes to the understanding of the effect of exercise on balance confidence and the relationship between change in balance confidence and change in objective measures of physical function.

## Chapter Four:  Part One

### 4.1 Introduction[2]

Osteoporosis is a major health problem affecting approximately 24 million American women (303). This disease is characterized by bone mineral at a level that is incapable of maintaining structural integrity of the skeleton.  As those with this bone disease are highly susceptible to sustaining fractures from falls, fall prevention warrants attention in the management of osteoporosis.  Despite this apparently self-evident connection, very little fall-related research has been completed in populations with osteoporosis.

Individuals with osteoporosis often report back pain and there is evidence to suggest that back pain has a negative influence on both postural stability (291,292) and functional mobility (293).  For example, healthy adults/older adults with chronic low back pain had greater standing postural sway (291,292) and reduced gait speed (293) than their counterparts without back pain.  Both of these variables are well-established fall risk factors (287,290).  However, whether the same relationship exists in those with osteoporosis has not been studied.

Osteoporosis-related back pain is likely to be multifactorial.  Kyphosis (304) and vertebral compression fractures (305,306) may cause pain in osteoporosis and both these factors influence postural stability (296) and functional mobility (296,307-309).  Kyphosis was associated with increased postural sway in six women with kyphosis compared to 10 controls (296).  It was also associated with reduced gait and stair climbing function in a cross-sectional study of 231 community-dwelling older individuals (307). Ten women with confirmed vertebral fractures had reduced maximal trunk torque, spine motion, functional reach, mobility skills, and gait speed in a cross-sectional study comparing them with 10 age- and race-matched subjects without fractures (309).   The number of recent vertebral fractures predicted poor performance in functional reach and gait speed in 569 postmenopausal women (308).  These studies demonstrate that kyphosis and vertebral compression fractures can be associated with impairments that

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could increase fall risk. Thus, the purpose of this study is to examine the association between back pain and postural stability and functional mobility in a group of older women with osteoporosis.

## 4.2 Methods

### 4.2.1 Participants

Individuals in this cross-sectional study of back pain and fall risk factors also participated in a prospective study examining the effects of a community-based exercise program on fall risk factors that has been reported elsewhere (74) and is not part of this thesis. Eligible participants were identified from a computerized database of community-dwelling women who had been referred for bone densitometry at the BC Women's Hospital and Health Centre Osteoporosis Program between 1996 and 2000. The database identified women who were: 1) aged 65 to 75, 2) resident within Greater Vancouver, Canada, and 3) had osteoporosis by DXA (Lunar Corp, Madison, WI) at the total hip and/or lumbar spine using the World Health Organization definition (areal BMD T-score at least 2.5 standard deviations below young normal sex-matched areal BMD of the Lunar reference database) (310).

Four hundred and fifty-six women met the above initial screening criteria and were invited by letter to participate in the exercise intervention study (74). Interested individuals were interviewed by phone to ensure that they met all study entry criteria. These were that the participant 1) was at least 5-years postmenopausal; 2) weighed less than 130% of ideal body mass; 3) did not expect to be absent from the city for more than 4 weeks in the upcoming year; 4) had no contraindications to undertaking physical exercise; and 5) was not currently engaging in a regular exercise program. Individuals who met all study entry criteria were invited to attend a group information session. A total of 108 (24% of total potential participants) women attended a group information session where the entry criteria were again checked. Eight women declined to participate because of time constraints and three declined because they wished to take an exercise class rather than risk potentially being randomized to the control (non-exercising) group. Consent was obtained at the end of the information session. Ninety-seven women (21% of total potential participants) agreed to participate in the prospective study (74) that is not part of this thesis. A

rheumatologist conducted a clinical neurological and musculoskeletal examination on all 97 participants. Four women were excluded from this cross-sectional analysis due to the presence of a neurological condition (2 due to stroke and 2 due to Parkinson's disease).

The study was approved by the University of British Columbia Clinical Research Ethics Board and the Research Committee of the Children's and Women's Hospital of British Columbia. All participants provided written informed consent prior to participating in the study.

### 4.2.2 Measurements

4.2.2.1 Descriptive Variables

Trained research assistants interviewed all participants to establish baseline measures for the prospective portion of the study. Age, standing height, and body mass were measured in all participants and body mass index (BMI, kg/m$^2$) was calculated. Duplicate measures of standing height (without shoes) to the nearest millimeter, using a customized wall-mounted stadiometer were taken. Stretch stature for standing height was measured by the standard method, by applying gentle upward traction from the base of the mastoid processes. Body mass was assessed with an electronic scale to the nearest 0.1 kg. For both height and body mass, duplicate measures was taken unless measures differ by $\pm$ 0.4 cm (height) or $\pm$ 0.2 kg (mass), when a third measurement was made. The average of two values or the median of three values was used for statistical analysis.

A self-reported history of falls in the past week and past year period was obtained from each of the 93 participants. As health status can affect both postural stability and functional mobility, a history of selected medical conditions was obtained by asking all participants if a physician had formally diagnosed them. For this cross-sectional analysis reported in this chapter (Part I), I controlled for the comorbid conditions of rheumatoid arthritis and osteoarthritis that were categorised as dichotomous variables: present (yes) or absent (no). The presence and the primary locations of each type of arthritis were confirmed in all cases by physician examination and a physician review of the participants' BC Women's Hospital and Health Centre Osteoporosis Program medical charts.

I recorded the chronicity of osteoporosis, defined as the number of years since initial diagnosis (either by DXA or X-ray) of the disease for each participant. In addition, a history of confirmed vertebral compression fractures (by radiography) was obtained from all participants. A physician review of the participants' medical charts confirmed chronicity of osteoporosis and vertebral compression fractures.

Current back pain intensity and its related disabilities were assessed with the Oswestry Low Back Pain Disability Questionnaire (ODQ) (311). The ODQ has a high test-retest reliability (311) (r = 0.99) and intraclass correlation coefficient (ICC = 0.83) (312). As well, it has been shown to be a valid assessment tool for chronic pain and low back pain individuals (312). The ODQ has ten sections (5 points each section) assessing pain intensity and pain-related disabilities in personal care, lifting, walking, sitting, standing, sleeping, social life, and sex life. The sex life question was removed because of a high rate of none-response from the participants. Thus, 45 points was the maximum possible score in this study with zero indicating no back pain.

The current physical activity level of each participant, in hours per week, was ascertained with Blair's interview-based seven-day physical activity recall questionnaire (313). This questionnaire was developed and administered in a community health survey, a randomized controlled trial, and two worksite promotion programs during 1979 to 1982. Energy expenditure estimates were derived from the questionnaire (314). In a one year randomized exercise trial, this physical activity recall detected increases in energy expenditure in the exercise group and was positively associated with miles run during training (313). The questionnaire has three intensities of physical activity: moderate, hard, and very hard. All participants, except for two, reported physical activity at the moderate intensity. Thus, all statistical analyses were confined to this intensity of physical activity. Examples of moderate intensity of physical activity as provided by the questionnaire are (313):

1. Occupational tasks such as delivering mail, house painting, and truck driving (making deliveries, lifting and carrying light objects).

2. Household activities such as raking the lawn, sweeping and mopping, mowing the lawn with a power mower, and cleaning windows.

3. Sport activities such as brisk walking for pleasure or work, golf, walking and pulling or carrying clubs, and callisthenics exercises.

4.2.2.2 Physiological Fall Risk Factors

Postural stability was assessed using the Equitest computerized dynamic posturography platform (Neurocom International, Clackamas, Ore) to determine response to sensory perturbations (Sensory Organization Test). The sensory organization test (SOT) consisted of three consecutive, 20-second trials of six combinations of visual and support surface conditions. The platform's visual surround and support surface moved in response to the subject's sway (sway referencing). The visual surround either remained stationary or, in the sway referenced conditions, provided inaccurate visual input. Similarly, during the sway referenced support conditions, the platform movement maintained an approximately 90 degrees angle at the ankle, providing inaccurate proprioceptive information. Equilibrium scores were calculated for each of the sensory conditions. The equilibrium score, a measure of postural stability, was based on the degrees of offset of the subject from the centered position in the anterior-posterior plane. Degrees of offset ranged from 8.5° forward to 4° backward. The equilibrium score measures peak to peak sway normalized to a maximum of 12.5° that ranged from 0 (when the subject exceeded the limits of stability and fell over) to 100 (no sway).

Each participant underwent two sequences of trials within one test session to overcome learning effects. As it has been shown to differentiate between older nonfallers from fallers, the composite balance score (average of all six conditions) of the second trial was used as an indicator of postural stability (315). In my pilot study of 10 older women between the ages of 65-75 years old, the test-retest reliability of the composite balance score was superior to the test-retest reliability of the individual test conditions. The ICC of the composite balance score was 0.91 (95% CI 0.64 to 0.98).

Functional mobility was tested by a figure-of-eight test that involved two cones placed 10 meters apart. A hand-held stopwatch measured the time it took to traverse two laps of the course as fast as possible. The best attempt of two trials was recorded. The result was converted to speed (m/sec) and then normalized to leg length (m). This test correlated significantly with stair-climbing capacity and quadriceps strength (316).

### 4.2.3 Statistical Analyses

Data were analyzed using SPSS (Windows Version 8.0). Data were checked with scatterplots to eliminate errors and outliers (greater than 3 SD above or below the mean). Descriptive data are reported for variables of interest (mean, SD, and range). I determined the level of association between the following variables using the Pearson's product moment correlation coefficient: age, back pain, BMI, self-report of physical activity level, composite balance score, and normalized figure-of-eight speed. The level of association between the dependent variables (postural stability and functional mobility) and the following independent dichotomous variables using the point biserial correlation coefficient (317) was also determined: a history of vertebral fracture (yes/no), osteoarthritis (yes/no), and rheumatoid arthritis (yes/no). The level of significance was set at $p \leq 0.05$.

I constructed two stepwise regression models to determine the most robust predictors of 1) postural stability (composite balance score), and 2) functional mobility (normalized figure-of-eight speed). Independent variables entered were: age, back pain, BMI, osteoarthritis, and rheumatoid arthritis. These variables were checked for multicollinearity. The independent variables were chosen based on the Pearson's product moment correlation results and biological association and were entered in the model at a significance level of $p \leq 0.05$ and removed from it at $p \geq 0.1$. Standardized residual values were checked for the fit of the regression model (for a good fit, 99% of standardized residuals should be within $-2.58$ and $+2.58$) and to ensure that they were of random pattern (318).

### 4.3 Results

#### 4.3.1 Characteristics of Participants

Characteristics for the 93 women are presented in Table 9. All participants had normal neurological and musculoskeletal function. Twelve women (13%) had at least one previously diagnosed vertebral fracture. Two women (2%) had fallen once in the last seven days and eight women (9%) had fallen once in the last year. Seventy women (75%) reported back pain. Twelve women (13%) had rheumatoid arthritis and thirty-eight women (41%) had osteoarthritis. No participants had an active flare-up of rheumatoid arthritis at the time of measurement and there was no clinical evidence of loss of function in the affected joints. Of the thirty-eight women with mild osteoarthritis, twelve women had the condition in their lumbar spine and fourteen had the condition in the lower extremities (such as the knee and hip joints).

#### 4.3.2 Correlation Coefficients

Correlations between the variables of interest are shown in Table 10. Postural stability and functional mobility were moderately correlated ($r = 0.55$; $p < 0.001$). Back pain was significantly correlated with both postural stability ($r = -0.30$; $p = 0.004$) and functional mobility ($r = -0.35$; $p = 0.001$) (Figures 5 and 6). Age was also significantly correlated with postural stability ($r = -0.31$; $p = 0.002$) and functional mobility ($r = -0.38$; $p < 0.001$). Body mass index was correlated with functional mobility ($r = -0.26$; $p = 0.01$). Osteoarthritis was also correlated with functional mobility ($r = -0.27$; $p = 0.009$). Self-report of physical activity level and a history of vertebral compression fractures were not significantly correlated with either postural stability or functional mobility.

#### 4.3.3 Regression Analysis

Age was the dominant predictor of both postural stability and functional mobility, accounting for 9% and 14% of the variance, respectively (Table 11). After accounting for age, back pain explained another 9% of the variance in postural stability and 13% of the variance in functional mobility. After accounting for both age and back pain, osteoarthritis accounted for an additional 4% of the variance in postural stability.

The total variance accounted by the regression models was 22% for postural stability and 27% for functional mobility.

Table 9. Descriptive statistics for variables of interest (N = 93). Age in years (yr), height in centimetres (cm), mass in kilograms (kg), body mass index (kg/m$^2$), chronicity of osteoporosis (yr), back pain (Oswestry Disability Questionnaire score out of 45 points), level of physical activity in hours per week (hrs/wk), postural stability (composite score out of 100 points), functional mobility (normalized figure-of-eight speed in seconds$^{-1}$), and areal bone mineral density (BMD) t-score.

| Variable | Mean | SD | Range |
| --- | --- | --- | --- |
| Age (yr) | 69.4 | 3.2 | 65 to 74 |
| Height (cm) | 157.7 | 6.6 | 138.9 to 170.8 |
| Mass (kg) | 61.0 | 12.2 | 33.2 to 90.2 |
| Body mass index (kg/m$^2$) | 24.5 | 4.9 | 14.7 to 36.8 |
| Chronicity of osteoporosis (yr) | 3.9 | 2.8 | 0 to 12 |
| Back pain (max. 45 points) | 6.6 | 6.8 | 0 to 26 |
| Level of physical activity (hrs/wk) | 11.6 | 13.9 | 0 to 84 |
| Postural stability: Composite score (max. 100 points)* | 71.5 | 11.7 | 29 to 87 |
| Mobility: Normalized figure-of-eight speed (sec$^{-1}$) | 2.2 | 0.5 | 0.7 to 3.2 |
| Areal BMD T-score[†] | | | |
|     Total proximal femur | -2.0 | 0.8 | - 5.5 to 0.7 |
|     Lumbar spine | -2.7 | 1.2 | - 3.4 to 0.0 |

*The composite score is an indicator of postural stability with higher scores representing less sway.
†Standardized areal BMD compared with young healthy population based on LUNAR database.

Table 10. Pearson product moment correlations matrix between variables of interest. A history of vertebral fracture (Fracture), presence of rheumatoid arthritis (RA), presence of osteoarthritis (OA), self-report of physical activity level in hours per week (Activity), pain (Oswestry Disability Questionnaire score out of 45 points), body mass index in $kg/m^2$ (BMI), age in years, postural stability (composite score out of 100 points), and functional mobility (normalized figure-of-eight speed in $seconds^{-1}$).

| | Fracture | RA | OA | Activity | Pain | BMI | Age | Postural stability | Mobility |
|---|---|---|---|---|---|---|---|---|---|
| **Postural Stability** | -0.05 | 0.10 | -0.02 | 0.06 | -0.30* | -0.08 | -0.31* | - | 0.55† |
| **Mobility** | 0.02 | 0.13 | 0.27* | -0.01 | -0.35† | -0.26* | -0.38† | 0.55† | - |

*$p \leq 0.01$
†$p \leq 0.001$
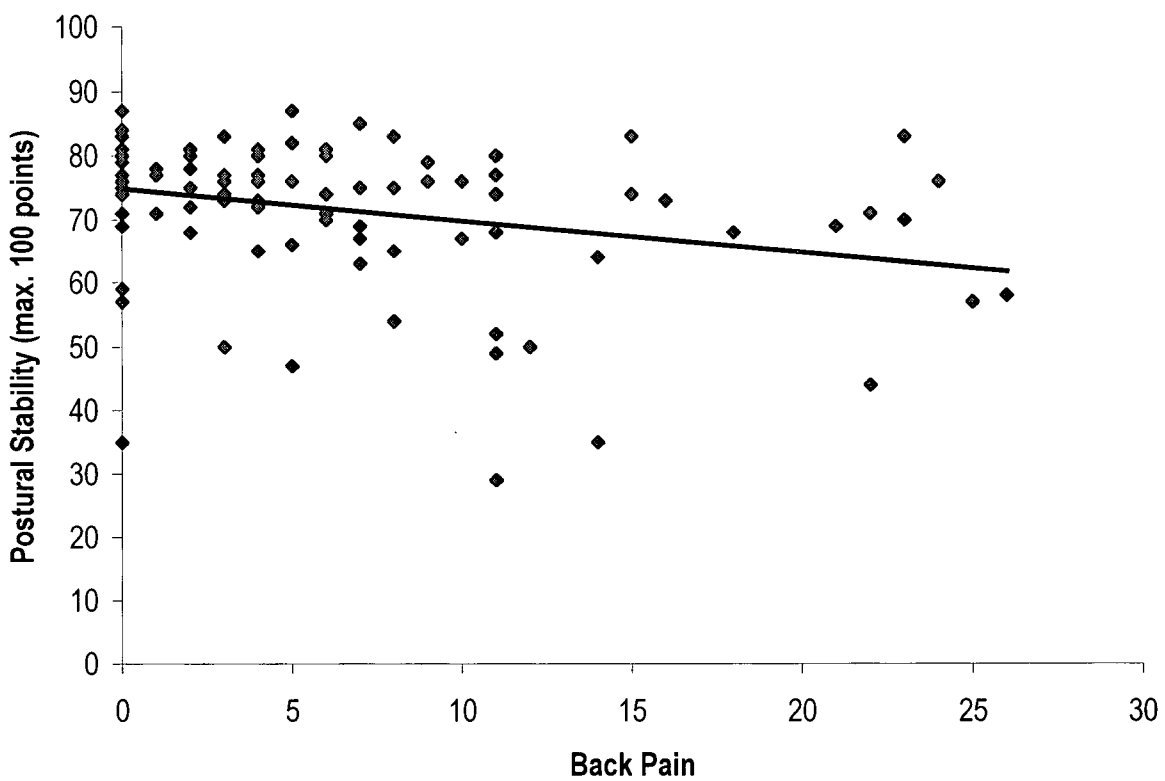
Figure 5. Relationship between back pain (Owestry Disability Questionnaire score, maximum pain and disability = 45points) and postural stability (composite score, maximum performance = 100 points) ($r = 0.30$, $p \leq 0.01$).
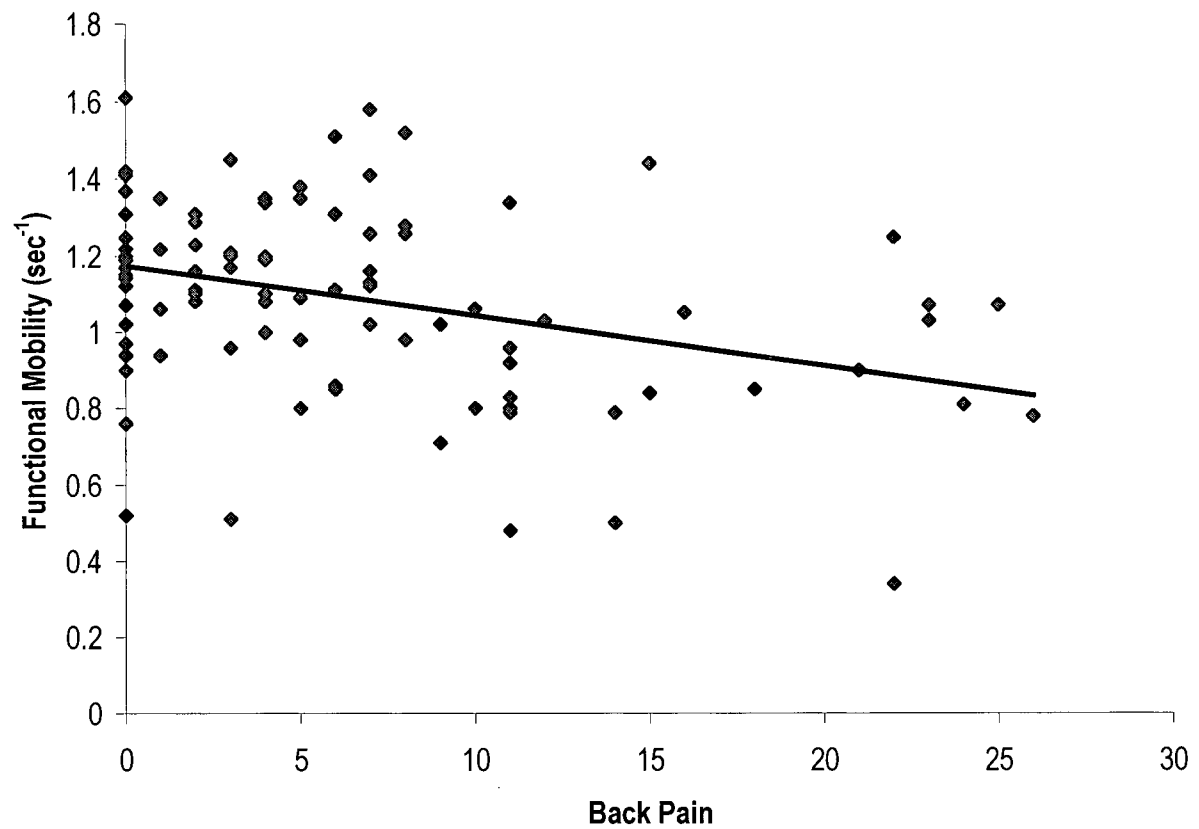
Figure 6. Relationship between back pain (Owestry Disability Questionnaire, maximum pain and disability = 45 points) and functional mobility (normalized figure-of-eight in seconds[-1]) (r = 0.35, p ≤ 0.001).

Table 11. Summary of regression models* for postural stability (composite balance score out of 100 points) and functional mobility (normalized figure-of-eight speed in seconds$^{-1}$) including standardized Beta coefficients and adjusted $R^2$.

| Variable | Model | Predictor | Standardized Beta | Adjusted $R^2$ | $R^2$ Change |
|---|---|---|---|---|---|
| Postural Stability | 1 | Age | -0.31 | 0.09 | |
| | 2 | Age | -0.33 | | |
| | | Pain | -0.31 | 0.18 | 0.09 |
| | 3 | Age | -0.37 | | |
| | | Pain | -0.43 | | |
| | | OA | -0.23 | 0.22 | 0.04 |
| Mobility | 1 | Age | -0.38 | 0.14 | |
| | 2 | Age | -0.41 | | |
| | | Pain | -0.38 | 0.27 | 0.13 |

*Variables entered into the stepwise regression models: age in years, presence of osteoarthritis (OA), presence of rheumatoid arthritis (RA), body mass index in kg/m$^2$, and back pain (Oswestry Disability Questionnaire score out of 45 points).

## 4.4 Discussion

The prevalence of back pain was very high (75%) in this cohort of older women with confirmed osteoporosis and to my knowledge this has not been reported previously. The prevalence of back pain has been reported to be 23% in older women with a recent hip fracture, a condition strongly indicative of osteoporosis (319). Hip fractures, however, can occur in the absence of metabolic bone disease (320). The prevalence of back pain found in the cohort appears to be much higher than the prevalence of back pain reported for age-matched counterparts without osteoporosis. Although the prevalence of back pain in older people without osteoporosis is not known with certainty, it likely ranges between 13% and 49% (321).

Many of the individuals who reported having back pain did not have a concurrent history of vertebral compression fracture. This finding concurs with studies showing that vertebral compression fractures are no more common in those with chronic back pain than in those without (319). Furthermore, only about one-third of new vertebral fractures come to medical attention, suggesting that most vertebral fractures are asymptomatic (322). I propose kyphosis, undiagnosed vertebral compression fractures, and factors unrelated to osteoporosis, as possible causes of back pain in this cohort.

Chronic back pain in osteoporosis has been attributed to ligament stretch secondary to kyphotic posturing. However, kyphosis was not associated with substantial chronic back pain in older women in a cross-sectional analysis (323). Thus, a number of studies have concluded that back pain in osteoporosis may be due to reasons not directly associated with the pathology of disease (319,324). Bone scintigraphic findings suggest that in addition to vertebral compression fractures, degenerative disk disease and facet joint arthropathy may also be important causes of back pain in individuals with spinal osteoporosis (325).

I found that pain was negatively associated with both postural stability and functional mobility. The finding of back pain's association with poorer postural stability and functional mobility in those with osteoporosis concurs with previous results in other populations (291-293). A number of mechanisms can be proposed as being consistent with this study's findings. In addition to receiving appropriate input from the sensory systems, normal joint range of motion, adequate strength and endurance of the lower extremity

and trunk, and an appropriate order of muscle recruitment are required for optimal postural control. Thus, any impairment of the musculoskeletal and/or the neuromuscular system may negatively impact both postural stability and functional mobility. For example, it is possible that those with back pain in this cohort adopted a hip and back strategy, as observed in healthy adults individuals with low back dysfunction (291), instead of the appropriate ankle strategy to maintain postural stability. Byl and Sinnott (291) attributed this change in recruitment strategy to the more posterior location of centre of force demonstrated by those with low back pain. With the centre of force posterior during standing, it is difficult to use the normal ankle strategy to maintain postural stability. Instead, one is required to flex and extend at the hips and the back to move the centre of pressure. This results in larger amplitudes of body sway.

As well, individuals with back pain may reduce their level of physical activity and as a result, become weak in key muscles required for postural stability and functional mobility. In a group of 217 women between the ages of 20 to 89 years old, self-reported physical activity levels were related to muscle strength of knee extensors, plantarflexors, and handgrip (326). However, I did not find a relationship between self-reported physical activity levels and measures of postural stability and/or functional mobility. This may be secondary to a lack of variability in the intensity of physical activity in this cohort as all but two participants exercised at a moderate intensity.

The negative association between age and postural stability and functional mobility has been examined extensively (290,293). In a study of 925 men and 890 women aged 70 years and above, age was negatively associated with gait speed (293). It is generally agreed that there are differences in postural stability between the young and old, especially when challenging perturbations are applied (290).

A significant portion (41%) of this cohort had osteoarthritis, a condition that was negatively associated with postural stability. Individuals with knee osteoarthritis have increased postural sway compared to healthy controls (327). Also, adults aged 65 years and older with chronic knee pain demonstrated significant declines in balance (and lower extremity strength) over a 30-month period (328).

The mechanism is proposed to be decreased proprioception and joint position sense secondary to the pathology of osteoarthritis.

The high prevalence of back pain in this cohort draws attention to pain as a symptom that warrants physician attention in the treatment of osteoporosis. As well, the finding of self-reported back pain as a determinant of postural stability and functional mobility, after accounting for age, suggests that this measure deserves attention when screening women with osteoporosis for fracture risk. As individuals with osteoporosis are prone to sustaining a fracture from a fall, preventing injurious falls is an essential component of managing this population. Thus, amendable factors that influence postural stability and functional mobility need to be identified in this high-risk fracture group. Intervention can reduce back pain in individuals with osteoporosis. Malmros et al. (81) examined the effects of a 10-week exercise program for individuals with osteoporosis on pain level, use of analgesics, quality of life, level of daily function, postural stability, and strength of trunk and quadriceps muscles. There was a significant reduction in use of analgesics and pain level during the training period.

## 4.5 Limitations

There are several limitations to this cross-sectional study. The total variance explained by the two regression models was modest, which suggest other variables are also important. Such variables could include: muscular strength of the lower extremities, proprioception of the lower extremities, and vestibular function. Second, the sample was confined to older women with osteoporosis. Future studies are needed to determine if back pain is similarly associated with postural stability and functional mobility in other populations of older people. Third, because I did not have a comparison (control) group (such as age-matched individuals with back pain but without osteoporosis) I am unable to ascertain whether this association of back pain with postural stability and functional mobility is unique to older people with osteoporosis or not. Finally, future prospective studies are needed to determine if pain management improves postural stability and functional mobility.

It is noteworthy, but not strictly a limitation, that all participants in this cross-sectional study had agreed to participate in a community-based six-month exercise program. It is possible that this group of older women with osteoporosis had less back pain and functional limitations than those who did not participate. Thus, the study may even underestimate the strength of the association between back pain and postural stability and functional mobility.

## 4.6 Summary and Future Directions

I found that back pain, after accounting for age, was a determinant of both postural stability and functional mobility in older women with osteoporosis. Specifically, back pain was negatively associated with both postural stability and functional mobility. Thus, back pain warrants attention when screening women with osteoporosis for fracture risk. Also, as exercise has the potential to reduce back pain (81), future randomized controlled trials in this population should examine whether exercise can improve back pain and whether its improvement is positively associated with changes in postural stability and functional mobility.

To further examine factors that influence fracture risk in older women with osteoporosis, Chapter Five details a cross-sectional comparison of three established fall risk factors between older women with osteoporosis and their age-matched healthy counterparts.

## Chapter Five: Part Two

### 5.1 Introduction[3]

As detailed in Chapter Two, osteoporotic fracture is a major health care problem worldwide (206) with many well-recognized risk factors. Some of them, such as age, female gender and Caucasian race, are not amendable. Others such as decreased muscle strength, impaired postural stability, decreased functional mobility (e.g., gait speed), and bone health (e.g., low bone mass), are amendable, even in older individuals. Thus, amendable risk factors for fracture can be largely divided into two domains: fall risk and bone health.

Fall prevention is well recognized as a vital component of fracture prevention as falls are the immediate cause of hip (7) and upper limb fractures (294). Hip fracture is a particularly disabling outcome of falling and about 80 to 90% of hip fractures in older people are secondary to falls (295). One group of individuals particularly at high risk of sustaining fall-related fractures are those with osteoporosis. Each standard deviation decrease in femoral neck bone density increases the age-adjusted risk of hip fracture 2.6 times (6). Whether this population is also at particular risk for falls, however, is not well-established. One study has suggested that older women with osteoporosis and kyphosis may have a greater risk of falling compared with their age-matched counterparts without osteoporosis (296) but it included few participants (six women with osteoporosis and kyphosis compared to five age-matched controls) with a relatively wide age range (52 to 85 years). Possible mechanisms that would increase fall risk in those with osteoporosis include postural changes related to osteoporosis (e.g., kyphosis), inappropriate balance strategies (296), self-imposed restrictions on physical activity secondary to fear of falling (329), general frailty (330), and low body mass (331).

To determine whether fall risk evaluation is warranted in the medical assessment of older women with osteoporosis requires a comparison of fall risk factors between those with osteoporosis and healthy

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[3] A version of this chapter has been published. Liu-Ambrose T, Eng JJ, Khan KM, Carter ND, McKay HA. Older women with osteoporosis have increased postural sway and weaker quadriceps than counterparts with normal bone mass: Overlooked determinants of fracture risk? Journal of Gerontology 2003; 18:M862-M866.

age-matched counterparts. Thus, the purpose of this cross-sectional study was to compare three established fall risk factors (quadriceps strength, postural stability, and functional mobility) between older women with osteoporosis and age-matched controls without osteoporosis. Previous investigators have identified these three fall risk factors as predictors of hip fractures (7,9,287).

## 5.2 Methods

### 5.2.1 Participants

Forty-two women between the ages of 64 and 75 years old participated in the present study. All participants were identified from a computerized database of women who had been referred for bone densitometry at the BC Women's Hospital and Health Centre's Osteoporosis Program between 1996 and 2000. From the database, women who were between the ages of 65 and 75 years old were identified. All potential participants were screened by phone to ensure the study's entry criteria were met. These were that the participant: 1) was at least 5-years postmenopausal; 2) weighed less than 130% of ideal body mass; 3) had no neurological conditions affecting balance, such as stroke and Parkinson's disease; 4) had no lower limb joint replacement; 5) was community-dwelling, 6) ambulated independently, and 7) was not currently engaging in a regular exercise program.

In the 21 women who formed the experimental ("osteoporosis") group, the diagnosis osteoporosis was confirmed by DXA (Lunar Corp, Madison, WI) at the total hip and/or lumbar spine using the World Health Organization definition (BMD T-score was at least 2.5 standard deviations below young normal sex-matched BMD of the Lunar reference database) (310). These 21 women were selected from a cohort of 97 women with osteoporosis described previously in Chapter Four, Section 4.2.1. They were chosen to match the age and physical activity level equivalency to the control group (see below). Of the 97 women screened for possible selection, four were excluded because of the presence of a neurological condition (e.g., 2 due to previous stroke and 2 due to Parkinson's disease).

The control ("no osteoporosis") group for this study consisted of 21 age- and physical activity level-matched women who met the entry criteria described above. These women are not part of any of the other

studies described in this thesis. The absence of osteoporosis at the total hip and lumbar spine was also confirmed by DXA (areal BMD t-score was greater than 1.0 standard deviation below young normal sex-matched areal BMD of the Lunar reference database).

The study was approved by the University of British Columbia Clinical Research Ethics Board and the Research Committee of the Children's and Women's Hospital of British Columbia. All participants provided written informed consent prior to participating in the study.

### 5.2.2 Measurements

5.2.2.1 Descriptive Variables

Standing height was measured to the nearest millimetre using a wall-mounted stadiometer, and body mass was measured with an electronic scale to the nearest 0.1 kilograms. For both height and mass, I used the mean of two values or the median of three values for analysis. Body mass index (BMI, $kg/m^2$) was also calculated.

Trained interviewers ascertained the number of currently prescribed medications and the number of falls in the past 4 weeks. The presence of osteoarthritis (of the hip and/or knee joint) was confirmed by health history (interviewer-based questionnaire) and physician examination. The current physical activity level of each participant, in hours per week, was ascertained with a seven-day physical activity recall questionnaire (313) that categorizes intensity of activity as either moderate, hard, or very hard. The majority of participants reported physical activity only at the moderate intensity. Thus, the experimental and the control groups were matched for number of hours per week of physical activity at moderate intensity. Examples of moderate intensity physical activity include household activities such as raking the lawn, sweeping and mopping, cleaning windows, and sport activities such as brisk walking and golf (313).

5.2.2.2 Physiological Fall Risk Factors

Quadriceps strength of the dominant leg was assessed using a strap assembly incorporating a strain gauge according to the method of Lord et al. (16). Dominance was assessed based on asking participants with which leg they would kick a ball. The kicking side was determined to be the dominant leg.

In three experimental trials, the participants, seated with the hip and the knee joint at 90 degrees of flexion, pulled against the strap assembly with maximal force and the greatest force was recorded to 0.5 kilograms. To account for total body size of an individual, the result was then normalized by height (m). The test-retest reliability (Pearson r) of this strength measurement was determined as 0.92 (Pearson r) in our laboratory for a similar-aged population of eight subjects.

Both postural stability and functional mobility were assessed by methods described previously in Chapter Four, Section 4.2.2.2, and thus, are only briefly described in this chapter. Postural stability was assessed using the Equitest computerized dynamic posturography platform (Neurocom International, Clackamas, Oregon). The sensory organization test (SOT) consisted of three consecutive, 20-second trials of six combinations of visual and support surface conditions. Each participant underwent two sequence trials within one test session to overcome learning effects. The composite balance score (average of all six conditions) of the second trial was used as an indicator of postural stability.

Functional mobility was tested by a figure-of-eight test that involved two cones placed 10 meters apart (332). A hand-held stopwatch measured the time it took to transverse two laps of the course as fast as possible. The best attempt of two trials was recorded. To account for size differences between individuals, the result was converted to speed (m/sec) and then normalized to leg length (m). This test has been shown to correlate with stair-climbing capacity and gait speed (316).

### 5.2.3 Statistical Analysis

Data were analyzed using SPSS (Windows Version 10.0). Data were checked with scatterplots to eliminate errors and outliers (greater than 3 SD above or below the mean). Dependent variables were checked for normality by calculating skewness and kurtosis. If the ratio of each statistic to its standard error is less than 2 or greater than –2, this indicates a normal population distribution (333). Descriptive data are reported for variables of interest (mean, SD, and 95% confidence interval (CI)). To minimize the overall probability of a Type I error, the overall significance level between groups in descriptive characteristics (age, height, body mass, BMI, number of medications used, and level of current physical

activity) and fall risk factors (dominant quadriceps strength, composite balance score, and functional mobility) was established using two separate multivariate analyses of variance (MANOVA). Between-group differences on individual variables of interest were then analyzed by analysis of variance (ANOVA). The level of significance was set at $p \le 0.05$.

## 5.3 Results

### 5.3.1 Characteristics of the Participants

Table 12 provides descriptive data and the results of the ANOVA comparing the descriptive characteristics of the two groups of women. The majority of the women were Caucasian (88%). There were four Asian women in the experimental group and one Asian woman in the control group.

Although the groups were not different overall (MANOVA, Wilk's lambda = 0.85, p = 0.43), the control group had a trend toward greater body mass (p = 0.06). There were no significant differences between the groups in age, height, BMI, the number of current medications used, or the level of current physical activity. Nine women in each group (43%) had osteoarthritis of the hip and/or knee joint. One participant in the control group had fallen once in the previous four weeks.

### 5.3.2 Physiological Fall Risk Factors

Table 13 provides descriptive data and the results of the ANOVA comparing the three fall risk factors. There was an overall difference between the two groups on the three physiological fall risk factors (MANOVA, Wilk's lambda = 0.77, p = 0.02). Dominant quadriceps strength and composite balance score were 18% (p = 0.03) and 11% lower (p = 0.01) respectively, in women with osteoporosis compared with controls. Functional mobility, however, was not significantly different between the two groups.

Table 12. Descriptive statistics and ANOVA results for characteristic variables (N = 42). Age in years (yr), height in centimetres (cm), mass in kilograms (kg), body mass index (kg/m$^2$), number of current medications, and level of physical activity in hours per week (hrs/wk).

| Variable | Osteoporosis Group (n = 21) | Control Group (n = 21) | ANOVA |
|---|---|---|---|
| | Mean (SD); Range | Mean (SD); Range | p value |
| Age (yr) | 68.3 (2.9); 65 to 75 | 68.6 (3.1); 64 to 75 | 0.76 |
| Height (cm) | 156.9 (7.0); 144.4 to 168.4 | 160.5 (8.1); 143.3 to 178.0 | 0.13 |
| Mass (kg) | 61.6 (14.7); 33.2 to 86.0 | 68.8 (7.9); 56.8 to 89.0 | 0.06 |
| Body Mass Index (kg/m$^2$) | 25.0 (5.8); 14.7 to 36.8 | 26.8 (3.7); 22.3 to 34.3 | 0.24 |
| Number of Medications | 1.9 (1.5); 0 to 5 | 2.7 (2.3); 0 to 8 | 0.22 |
| Level of Physical Activity (hrs/wk) | 20.5 (18.8); 1.5 to 84 | 20.6 (19.5); 1 to 84 | 0.98 |

Table 13. Descriptive statistics and ANOVA results for physiological fall risk factors (N = 42).  Adjusted dominant quadriceps strength (kg/m), postural stability (composite score out of 100 points), functional mobility (normalized figure-of-eight speed in $sec^{-1}$).

| Variable | Osteoporosis (n = 21) Mean (SD); Range | Control Group (n = 21) Mean (SD); Range | Difference Between Groups (N = 42) Mean (SD); 95% CI | ANOVA p value |
|---|---|---|---|---|
| Adjusted Quadriceps Strength (kg/m) | 14.6 (4.4); 7.0 to 23.0 | 17.8 (4.5); 7.7 to 26.5 | 3.2 (6.6); 0.2 to 6.2 | 0.03 |
| Postural stability (max. 100 points) | 70.9 (13.6); 29 to 87 | 79.4 (4.3); 69 to 88 | 8.5 (13.7); 2.3 to 14.7 | 0.01 |
| Functional Mobility ($sec^{-1}$) | 2.34 (0.47); 1.56 to 3.21 | 2.41 (0.41); 1.80 to 3.46 | 0.06 (0.65); -0.23 to 0.36 | 0.65 |

## 5.4 Discussion

Effective facture risk reduction in older people requires augmenting bone health and reducing fall risk. In this chapter, I report that women with osteoporosis had less quadriceps strength and poorer postural stability than women with normal bone density. These differences were present even though the study design ensured there were no differences between the groups in age and level of current physical activity. These data suggest that women with osteoporosis may be at increased fracture risk compared with age-matched counterparts not only because of lower areal BMD but also because of increased fall risk. In their large prospective study of fracture incidence (1789 men and women), Nguyen et al. (9) found that next to femoral neck areal BMD, quadriceps strength and postural stability were the best independent predictors of fracture. Specifically, a decrease of one standard deviation in femoral BMD and a one standard deviation decrease in postural stability were independently associated with a 2.4 fold and a 1.7 fold increase in risk of fracture, respectively.

Mechanisms that would be consistent with the observed differences in muscular strength and postural stability between these two groups of older women are:

1. Individuals with spinal osteoporosis tend to develop kyphosis over time (334). A kyphotic posture may displace the centre of gravity (COG) closer to the limits of stability (296). A displacement of the COG closer to the limits of stability will require greater efforts to maintain balance even with small perturbations, such as using a hip strategy instead of an ankle strategy. Compared to an ankle strategy, a hip strategy creates greater amplitudes of sway (335) and thus, lower composite balance scores. Whether this applied in the present study is not known as I did not measure kyphosis in this study.

2. Individuals with osteoporosis, with or without kyphosis, may have a preference for using a hip strategy to maintain balance even when an ankle strategy would be more appropriate (296). The reasons for this are not clear. Possible reasons include weakness of the key muscles involved in an ankle strategy (e.g., tibialis anterior) and impaired sensory feedback from the ankle joints. Lynn

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et al. (296) contend that the fall risk of an individual may increase if a hip strategy is used in lieu of an appropriate ankle strategy.

3. Fear of falling and fracture are common among those with osteoporosis (329) and this may result in a self-imposed reduction in physical activities, which, in turn, may lead to muscle weakness and postural instability (336,337). This appears to be a less likely explanation for this study's findings, however, as both groups had equivalent current physical activity level. Nevertheless, existing physical activity measures are imperfect (338,339) and the instrument used may have been insensitive to detect extant current differences. Also, significant biological differences may have existed as a result of past physical activity levels.

4. One of the risk factors associated with osteoporosis is general frailty (145). Thus, the experimental group (women with osteoporosis) may have been frailer than the control group (women without osteoporosis) even though there were no between-group differences in the number of participants with arthritis, fall history, and the number of medications being taken. There is yet no standard definition of frailty and I did not attempt to assess it in a comprehensive manner. Frailty can be considered a multidimensional construct that includes medical conditions, genetics, lifestyle, and socio-economic influences on health and function (330,340). The concept of frailty is different from the concept of "fear of falling" as the former suggests that individual are unable to partake in regular physical activity while the latter implies a choice not to, for fear of consequences. Future studies extending this work should attempt to measure frailty in detail via thorough medical evaluation and detailed measures of functional capacity (e.g., six-minute walk) and ability (e.g., activities of daily living assessment).

5. Low body mass is correlated with greater postural instability in older women (341). Mean body mass was 7.2 kilogram greater in the control group as compared with the experimental group. As low body mass is also a risk factor for osteoporosis (334), it is plausible that the association

between low body mass and fracture risk (342,343) could be related to both increased fall risk and low bone mass.

This finding of decreased postural stability in women with osteoporosis extends previous data that showed older women with osteoporotic vertebral compression fractures had reduced functional reach, an indirect measure of balance, compared with age- and race-matched controls who had no vertebral compression fractures (309). In that study, physical activity levels were also comparable between the two groups.

The lack of difference observed in functional mobility may be secondary to the lack of sensitivity of the figure-of-eight test to detect true differences between the two groups. Compared with the SOT task protocol, which progressively challenged an individual in a systematic manner, for the figure-of-eight test participants were allowed to either walk or run the course. Thus, even if true differences in functional mobility existed between groups, these may have gone undetected as the test protocol permitted a variety of ways of transversing the course.

## 5.5 Limitations

A key limitation of this study was that participants self-reported their level of physical activity. Although self-report measures of current physical activity are commonly used in research studies, they are unlikely to be as accurate as direct, objective and prospective measures of physical activity. As differences in current physical activity level may be the key basis for the observed differences in strength and postural stability between the two groups, it is important that future studies determine physical activity in an objective and prospective manner. Also, future studies assessing fall risk in older adults should use more comprehensive and valid outcome measures. I recommend determining and comparing overall fall risk using the Physiological Profile Assessment (PPA) © (16) instead of individual physiological fall risk factors. This outcome measure is discussed in Chapter Two, Section 2.1.5, and used in the research described in the following chapters. This approach would provide stronger evidence that women with osteoporosis have a higher risk of falling compare with those without osteoporosis as the PPA score predicts those at risk of

falling with 75% accuracy in both community and institutional settings (52,66,67). Furthermore, the present study did not ascertain variables, such as the degree of kyphosis, balance strategies, and fear of falling that would have helped to permit greater insights into possible mechanisms that underpin the findings.

The primary purpose of this study was hypothesis-generating and I have shown that there were differences in certain physiological fall risk factors between a sample population of women with and without osteoporosis. Thus, I recommend future studies to further delineate the mechanisms underpinning increased fall risk in those with osteoporosis. A clinical corollary of this study is that physicians treating women with osteoporosis should consider fall risk screening and if appropriate, referrals to fall risk reduction programs.

## 5.6 Summary and Future Directions

This cross-sectional study highlights that older women with osteoporosis may constitute a particularly high fracture risk group as in addition to having low bone density, they appear to have higher fall risk than their age-matched healthy counterparts. Thus, fall risk screening and, where appropriate, intervention may be prudent to prevent fractures in women with osteoporosis. Unlike pharmaceutical and nutrition interventions that aim to optimize bone mass in older people, exercise may influence multiple risk factors for fracture (i.e., reduce fall risk factors and augment bone health) simultaneously.

The studies reported in Chapters Four and Five highlight that women with osteoporosis present with increased fall risk in addition to their increased fracture risk. Exercise provides a potential vehicle to both effectively reduce fall risk and augment bone health. On the other hand, undertaking exercise could potentially increase fracture risk by encouraging inappropriate risk-taking behaviour, providing greater exposure to fall risk through increased physical activity, as well as potentially causing a transient increase in bone fragility if there is a phase of bone resorption prior to compensatory bone formation. Exercise also has the potential to cause soft tissue injuries, and aggravate arthritis. The effect of various types of exercise has not been tested in older, frail, people. Thus, the purpose of my next study was to test the effects of two types of exercise on fall risk (Chapter Six), bone health (Chapter Seven), and fear of falling

(Chapter Eight) in a cohort 10 years older than that of the previous studies and who also had low bone

mass (osteoporosis and osteopenia). Examining the feasibility and safety of such programs in this

population was also an important part of the research.

## Chapter Six: Part Three

### 6.1 Introduction[4]

Falls are a relatively common event in older people. Approximately 30% of individuals over 65 years of age fall at least once a year, and about half of those do so recurrently. Fall-related injuries and death in older people are a major health care problem worldwide, with the numbers continuing to rise (344). Thus, fall prevention in older people remains a major health care priority.

Falls are not random events (22) and occur, at least in part, due to physiological impairments, such as decreased postural stability, muscular weakness, and slowed reaction time (36). As discussed in Chapter Two, exercise can effectively reduce both fall risk factors and falls in older people by ameliorating physiological impairments. For example, Lord et al. (10) demonstrated that a community-based general exercise program improved postural stability, muscular strength, and reaction time in older women. Furthermore, both Tai Chi Quan (82) and a home-based strength and balance training program (95) have reduced the incidence of falls in community-dwelling older adults. However, exercise comes in many forms, and further research is needed to delineate the specifics of exercise prescription for optimal fall risk and fall reduction. Defining the components of exercise that are effective in reducing fall risk would provide some insight as to the possible underlying mechanisms by which exercise exerts its effect and allow those prescribing exercise to do so more effectively.

Fractures, especially of the hip, are particularly disabling consequences of falling (345). One group of individuals at particularly high risk of sustaining fall-related fractures are those with low bone mass. For example, each standard deviation decrease in femoral neck bone density increases the age-adjusted risk of hip fracture 2.6 times (6). Furthermore, my previous study (Chapter Five) showed that older women with osteoporosis may have an increased risk of falling due to greater impairments in postural stability and muscular strength compared with age-matched counterparts without osteoporosis (346). Thus, exercise

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programs aimed at reducing fall risk and falls may be particularly important for older people with low bone mass.

My colleagues in the UBC Bone Health Research Group and BC Women's Hospital Osteoporosis Program tested the effectiveness of a low-intensity general exercise program in reducing fall risk in a population of women with osteoporosis aged 65 to 75 years (74). These low intensity resistance, coordination and balance exercises were effective for improving strength and postural stability. I build on that work by conducting a 25-week, single-blinded, randomized controlled trial to compare the effectiveness of two types of group-based exercise programs (high-intensity resistance training and agility training) in reducing fracture risk in community-dwelling women aged 75 to 85 years of age with low bone mass. Data relating to fall risk are reported in this chapter, and the bone outcome measures are detailed in Chapter Seven.

## 6.2 Methods

### 6.2.1 Study Design

This was a randomized, controlled 25-week prospective study with three measurement periods (baseline, midpoint, and trial completion). The assessors were blinded to the participants' assignments. Figure 7 provides the overall schematic of the study.
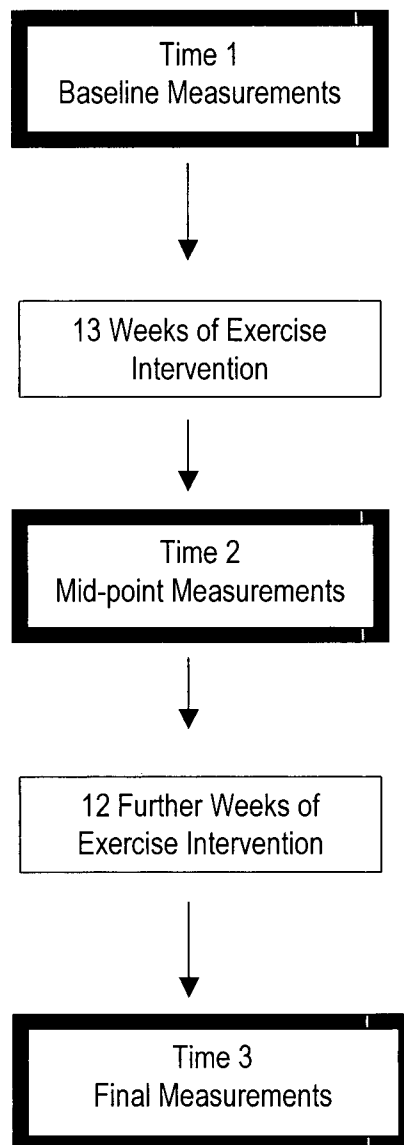
Figure 7. Overall schematic of study.

### 6.2.2 Participants

Eligible participants were identified from a computerized database of community-dwelling women who had been referred for bone densitometry at the BC Women's Hospital and Health Centre Osteoporosis Program between 1996 and 2002. All women aged 75 to 85 years who were residents of greater Vancouver and in whom osteoporosis or osteopenia had been diagnosed at the BC Women's Hospital and Health Centre (defined as a T-score at the total hip or spine at least 1.0 standard deviations below the young normal sex-matched areal bone mineral density of the Lunar reference database) (310) were identified. Please note that this was the same method used to identify individuals for Parts I and II (Chapters Four and Five) but I recruited a 10-year older cohort with a broader areal BMD entry criteria (T-score $\leq$ 1.0). In addition, the Osteoporosis Society of Canada, BC Division, provided a list of individuals with low bone mass who had provided permission to be approached for research studies. I mailed 683 letters of recruitment to the women identified from these databases and advertised in local newspaper and radio to aid in recruitment. Low bone mass was confirmed in those volunteers recruited in this manner by a DXA scan in our laboratory.

Interested individuals were screened by a standardized telephone interview, which included the revised physical activity readiness (Par-Q) questionnaire (347), and were then invited to an information session where a physician (KMK) also screened all potential participants by medical history. I excluded women who were: living in care facilities, of non-Caucasian race (because of the bone research questions), regularly exercising twice weekly or more, had a history of illness or a condition that would affect balance (e.g., stroke and Parkinson's disease), were unable to safely participate in the exercise program, or had a Mini Mental State Examination (MMSE) (348) score of $\leq$ 23. The flow chart (Figure 8) shows the number of participants in the treatment arms at each the stage of the study.

The study was approved by the University of British Columbia Clinical Research Ethics Board and the Research Committee of the Children's and Women's Hospital of British Columbia. All participants provided written informed consent prior to participating in the study.
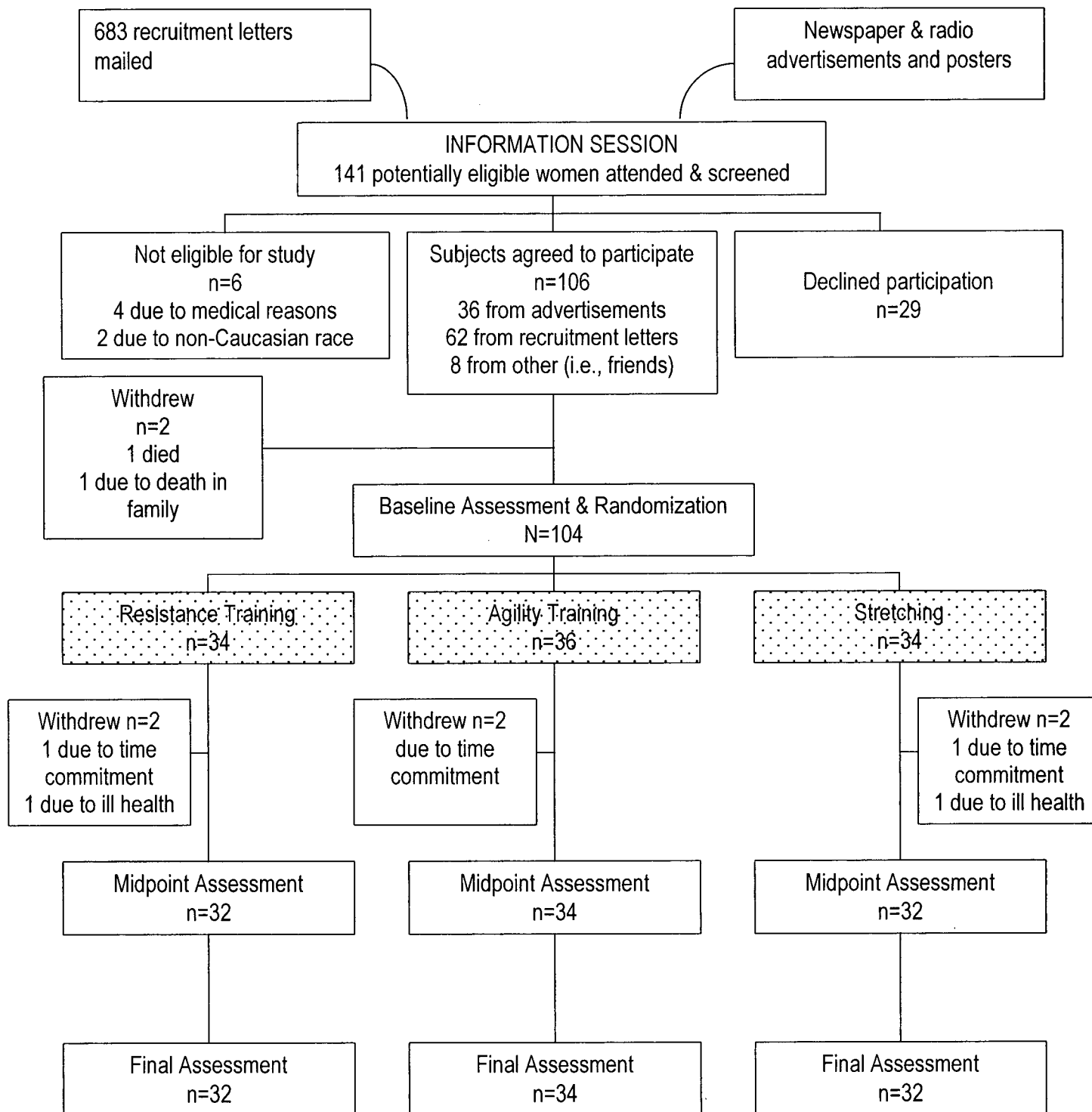
Figure 8. Flow chart outlining numbers of participants in each study arm.

### 6.2.3 Measurements

6.2.3.1 Descriptive Variables

#### Height and Mass

Standing height was measured to the nearest millimetre using a wall-mounted stadiometer, and body mass was measured with an electronic scale to the nearest 0.1 kilograms. For both height and mass, I used the mean of two values or the median of three values for analysis.

#### Questionnaires

General health was assessed with questions from the Canadian Multicentre Osteoporosis Study (CaMOS) questionnaire (349) that relate to current medication use, current supplement use, the presence of medical conditions known to be fall risk factors (such as osteoarthritis), and history of falls. This questionnaire was administered at baseline by trained interviewers. As well, all participants underwent a physician assessment (Dr. Lynda Thayer) to confirm current health status and health history. Use of walking aid was also recorded.

Cognitive state was assessed using the Mini-Mental State Examination (MMSE) (348). The MMSE is the most widely used insturment to rapidly assess the cognitive status of older indivudals, in both clinical and research settings. The MMSE comprises 11 questions assessing orientation to time and place, attention, immediate and short-term recall, language and visual-graphic abilities. Its psychometric properties have been studied by many investigators and were throughly reviewed by Tombaugh and McIntyre (350).

#### Vision and Peripheral Sensation

Visual acuity, both high and low contrast, was assessed at a test distance of three meters (16). Corrected acuity was determined binocularly and measured in terms of the minimum angle resolvable in minutes of arc. Tactile sensitivity was assessed with a pressure aesthesiometer (16). Filaments of varying thickness were applied to the center of the lateral malleolus and measurements are expressed in logarithms of milligrams pressure.

### 6.2.3.2 Primary Outcome Measure: PPA Fall Risk Score

Participant's fall risk was assessed at the three measurement periods using the short form of Physiological Profile Assessment (PPA) © (16). Table 14 describes the tests from the short-form PPA assessment. A PPA fall risk score was calculated for each individual. In our laboratory, the ICC of the PPA fall risk score for a cohort of 21 women aged 75 to 85 years was 0.78 (95% CI 0.46 to 0.91).

Table 14. Physiological profile assessment short-form assessment.

| PPA Task | Description | Measure |
|---|---|---|
| Postural Stability | Individuals were asked to stand as still as possible for 30 seconds on 15cm thick medium-density foam rubber mat with their eyes open, wearing the Lord swaymeter (66). The device consists of a 40-cm long rod with a vertically mounted pen at its end. The rod is attached to the participants by a firm belt and extends posteriorly. The pen records sway on a sheet of millimetre graph paper fastened to the top of an adjustable height table. | Total sway path (mm) was determined from the path traced. |
| Quadriceps Strength | A simple strain gauge was used to assess dominant quadriceps (isometric) strength to the nearest 0.5 kilogram. Participants were seated with the hip and the knee joint at 90 degrees of flexion. | The best of three trials (kg). |
| Hand Reaction Time | Used a light as the stimulus and depression of a switch by the finger as the response. | The average of 10 trials (msec). |
| Proprioception | Seated participants with eyes closed were asked to align the lower limbs on either side of a 60 by 60 cm by 1-cm-thick clear acrylic sheet standing on edge and inscribed with a protractor. | The difference (deg) in matching the great toes. |
| Edge Contrast Sensitivity | The Melbourne Edge Test was used to assess this aspect of visual function. This test presents 20 circular patterns containing edges with reducing contrast. Correct identification of the orientation of the edge on the patches provides a measure of contrast sensitivity in decibel units (dB), where $dB = -10\log_{10}$ contrast. | Number of the last correctly identified circle (dB). |

6.2.3.3 Secondary Outcome Measures

Secondary outcome measures were included to assess lower limb function in domains not assessed by the short-form PPA as well as a measure of overall general balance and mobility.

**Lower Limb Strength and Reaction Time**

Isometric ankle dorsiflexion was assessed in a seated position with the foot secured to a footplate and the angle of the knee positioned at 120 degrees. In three trials, the participant attempted maximal dorsiflexion of the ankle and the greatest force was recorded (16). Foot reaction time was assessed with a light as a stimulus and a foot-press as the response (16).

**General Balance and Mobility**

General balance and mobility was assessed using the Community Balance and Mobility Scale (CB&M Scale) (351). This scale is a performance-based balance and mobility measure consisting of 12 items each rated at a 5-point scale (85 points maximum). It includes items such as timed single leg stand, tandem walking, and stair mobility. This scale was chosen because present balance and mobility measures do not adequately assess higher levels functioning expected in community-dwelling older people (315,352). Published test-retest reliability for the Community Balance Mobility Scale indicates a high agreement between tests with an ICC of 0.98 (351). The internal consistency of the scale is also very high (Cronbach's alpha = 0.96) (351).

6.2.3.4 Physical Activity Level

Each participant's current level of physical activity was determined at the three measurement periods with the Physical Activities Scale for the Elderly (PASE) questionnaire (353,354). The PASE is a 12-item scale for those who are 65 years of age and older that measures the average number of hours per day spent participating in leisure, household, and occupational physical activities over the previous 7 day period. For example, under the category of leisure activities, the amount of time individuals spend each week 1) walking, 2) in light sport and recreational activities, 3) in moderate sport and recreational activities,

4) in strenuous sport and recreational activities, and 5) exercising to increase muscular strength and endurance are all recoded and details of the activities are logged so that the investigator can ensure correct classification (light, moderate, or strenuous). Time spent participating in each activity area is multiplied by a weighted value that reflects the amount of energy expended by an older adult engaged in that activity (355). These weighted values are then summed to yield a composite PASE score. Washburn et al. (355) reported that scores may range from 0 to 400 or higher.

The PASE is a valid and reliable measure of physical activity among older adults with no serious physical limitations (353). In a sample of 222 individuals, PASE scores were significantly correlated with postural balance, grip strength, leg strength, self-assessed health status, and the Sickness Impact Profile (353). The test-retest reliability coefficient of the PASE was 0.75 for self-administration and 0.68 when administered during a telephone interview (353).

6.2.3.5 Compliance and Falls

Adherence with the assigned exercise program was recorded for each participant and compliance is expressed as the percentage of the 48 classes (maximum number of classes) attended. I encouraged compliance with bi-weekly newsletters that highlighted participants' birthdays, weekly draws for prizes, and social outings.

All 98 participants were asked to keep a fall calendar throughout the intervention period. Participants were asked to mail the calendar sheets to the UBC Bone Health Research Laboratory at the end of each month. If a calendar sheet was not received within the first week of the following month, a telephone call was made. If a fall was noted in the calendar, I would call the individual to ascertain the details of the event. A fall was defined as an event that "results in a person coming to rest inadvertently on the ground or other lower level and other than as a consequence of...sustaining a violent blow, loss of consciousness, sudden onset of paralysis, as in a stroke, (or) an epileptic seizure" (17). This is generally accepted as the standard definition for clinical trials.

### 6.2.4 Randomization

After baseline measurement, participants were randomly assigned (by random draw) to one of three groups: Resistance Training, Agility Training, and Stretching (sham exercise). Randomization was stratified by baseline postural stability (total sway path; eyes open standing on foam), baseline total hip areal BMD, and the use of bisphosphonates (yes/no). Participants were stratified on the latter two variables because of the bone outcome measures (Chapter Seven).

### 6.2.5 Sample Size

The required sample size for this study was estimated based on predictions of 20% for the Agility Training group, 10% for the Resistance Training group, and 0% change for the Stretching group in the PPA's fall risk score. Assuming a 30% attrition rate and using an alpha level of $\leq 0.05$, recruiting 30 participants per group would provide a power of greater than 0.80 to detect a 10% difference between groups. This sample size was also adequate for the bone outcome measures (see Chapter Seven).

### 6.2.6 Exercise Intervention

I am a licensed physical therapist and I designed the exercise intervention programs. The head instructor responsible for the implementation of the exercise programs was Connie Waterman, Director of the BC Women's Hospital Osteofit Program. The exercise intervention began one week after the baseline measures were administered. Participants were required to attend their assigned exercise class twice weekly. All classes were held at a YMCA community centre and led by fitness instructors with valid certification by the BC Recreation and Parks Board to instruct seniors (BCRPA; Third Age) and by the BC Women's Hospital Osteofit Training Program. The classes were 50 minutes in duration, with a 15-minute warm-up, 20 minutes of core content, and a 15-minute cool down. The instructor to participant ratio was 1:2 for the Resistance Training class, 1:3 for the Agility Training class, and 1:4 for the Stretching class. Attendance was recorded daily by the head instructor of each class.

Table 15. Schedule of exercise classes (available for all 25 weeks) and instructor to participant ratio.

| Time | Monday | Tuesday | Wednesday | Thursday | Friday |
|------|--------|---------|-----------|----------|--------|
| 11:00 – 11:50 | Stretching (1:4) | Resistance (1:2) | Stretching (1:4) | Resistance (1:2) | No Classes |
| 12:00 – 12:50 | | Agility (1:3) | | Agility (1:3) | No Classes |
| 1:00 –1:50 | Resistance (1:2) | | Resistance (1:2) | | No Classes |
| 1:20 – 2:10 | Resistance (1:2) | | Resistance (1:2) | | No Classes |
| 1:30 to 2:20 | | Resistance (1:2) | | Resistance (1:2) | No Classes |
| 2:30 – 3:20 | Agility (1:3) | Stretching (1:4) | Agility (1:3) | Stretching (1:4) | No Classes |

## 6.2.6.1 Resistance Training

The protocol for the Resistance Training group was progressive and high-intensity in nature with the aims of increasing muscle strength in the extremities and trunk. Both a Keiser® Pressurized Air system (Keiser Corporation, Fresno, CA, USA) and free weights were used to provide the training stimulus. Participants underwent a 2-week familiarisation period with the equipment and the exercises. The Resistance Training exercises included: biceps curls, triceps extension, seated row, latissmus dorsi pull- downs, mini-squats, mini-lunges, hamstring curls, calf raises, and gluteus maximus extensions on a mat.

The intensity of the training stimulus was initially set at 50 to 60% of 1RM (repetition maximum) where the 1RM was determined at week two, with a work range of two sets of 10-15 repetitions and progressed to 75 to 85% of 1RM at a work range of six to eight repetitions (two sets) by week four. The training stimulus was increased using the 7RM method (356), when two sets of six to eight repetitions were completed with proper form and without pain or discomfort. Squats, lunges, and gluteus maximum extensions, however, did not follow the above guideline. These three exercises were performed initially with body mass and loading was increased only when proper form was maintained for two sets of 10 repetitions. The number of sets completed and the load lifted for each exercise were recorded for each participant at every class.

6.2.6.2 Agility Training

The Agility Training program included activities that emphasized quick starting and stopping movements, quick changes in directions, and choice reaction. The aims of the Agility Training protocol were to challenge: 1) hand-eye coordination, 2) foot-eye coordination, 3) dynamic balance, 4) standing and leaning balance and 5) psychomotor performance (reaction time). I devised ball games, relay races, dance movements, and obstacle courses to achieve these goals. A logbook was maintained detailing the content of each week's classes and will be compiled into a formal manual by head fitness instructor, Connie Waterman.

Schmidt (357)described elements that should be considered in the design of such training programs to ensure adequate carryover of learned skills to functional activity. These elements include the use of a variety of movement patterns and the use of variable practice methods. The use of different movement patterns should be included to provide an opportunity for an individual to discover more effective patterns to solve movement problems. This concept was applied in the development of the Agility Training program by incorporating a variety of agility and balance tasks, such as crossover walking (with changes in direction), backward and forward tandem walking, and practising sudden starts and stops with verbal instructions as in the popular children's game "Simon Says". Variable practice methods involve changing the sequence of tasks that will be practiced as well as having an individual practice a skill under various conditions, such as various speeds and degrees of difficulty. Variable practice is believed to enhance skill retention and to improve an individual's ability to solve novel movement problems. Various practice methods were applied in the Agility Training program by using various speeds, directions, and base of support. Due to the potential risk of falls occurring in the Agility Training class, participants were given KPH® (Tampere, Finland) hip protectors and all instructors provided very close supervision and 'spotting' as in gymnastics training.

6.2.6.3 Stretching (Sham Exercise)

The Stretching classes consisted of upper and lower limb stretching exercises, deep breathing and relaxation techniques, and general posture education. There is no evidence that these exercises reduce fall risk (106). This group served to control for confounding variables such as physical training received by

traveling to the community centre for the twice-weekly classes, social interaction and changes in lifestyle secondary to study participation.

### 6.2.7 Monitoring of Adverse Events

After each exercise session, participants were questioned about the presence of any adverse effects, such as musculoskeletal pain or discomfort. Modifications in the training program were made on an individual basis as needed. Any falls that occurred during the classes were recorded. All instructors also monitored participants for angina (chest pains) and shortness of breath.

### 6.2.8 Statistical Analysis

The data were analysed on an intention to treat basis, using SPSS (Windows Version 11.0) statistical software. Data were checked with scatterplots to eliminate errors and outliers (greater than 3 SD above or below the mean). Dependent variables were checked for normality by calculating skewness and kurtosis. If the ratio of each statistic to its standard error is less than 2 or greater than –2, this indicates a normal population distribution (333). Variables that were not normally distributed (sway, hand and foot reaction time) were transformed using natural logarithm before comparisons between the groups were made. Comparisons of group characteristics and baseline scores were undertaken using a Chi Square test for differences in proportions and ANOVA for differences in means. The fall risk scores, fall risk score components, secondary outcome variables, and PASE scores measured at the 13- and 25-week retests were compared by forced entry multiple linear regression analysis, with baseline scores and experimental group included as independent variables in the models. This analysis procedure provides a more precise indication of the treatment effect than provided by group by time ANOVAs (333). Post-hoc analyses were then performed where there were significant main effects use Scheffe corrections. Multivariate analysis of variance (MANOVA) with repeated measures was used to examine whether there were changes in fall risk at the end of the trial compared with baseline and 13-weeks in the Agility and Resistance Training groups. In these analyses, polynomial contrasts were selected giving measures of linear and quadratic (i.e., non-linear or asymptotic) trends. Finally, Pearson correlations were computed to determine if changes in the

squat load normalized for body mass (load change/mass) between the beginning and at the end of the intervention period was related to reductions in postural sway in the Resistance Training group.

## 6.3 Results

### 6.3.1 Descriptive Variables, Exercise Compliance, and Physical Activity Levels

The mean age of the cohort was $79 \pm 3$ years. The three groups did not differ in any of the descriptive variables (Table 16). In the entire study cohort, compliance to the exercise classes was 83%. The Resistance Training group had an average compliance of 85%, the Agility Training group 87%, and the Stretching group 79%.

Physical activity levels (PASE scores) increased during the 25-week intervention period within all three groups ($p < 0.001$). However, these changes did not differ significantly among the groups ($p = 0.80$), and changes in PASE scores were not significantly related with changes in primary or secondary outcome measures ($r \leq 0.11$, $p \geq 0.27$).

### 6.3.2 PPA Fall Risk Score, Fall Risk Components and Secondary Outcome Measures

Table 17 shows the baseline, 13-week and 25-week retest results for the fall risk scores, fall risk score components and secondary outcome measures for the three study groups. The regression analyses revealed a significant difference in one measure only (scores in the CB&M Scale) at the mid-point of the trial. Post-hoc test showed that the Agility Training group showed significant improvements in this measure compared with the other two groups.

At the end of the trial there were group differences for the fall risk score and postural stability on the compliant foam rubber mat. The groups did not differ on the remaining components of the PPA or secondary outcome measures, although for both reaction time tasks, the associations approached statistical significance – hand reaction time ($F_{2,94} = 2.49$, $p = 0.09$) and foot reaction time ($F_{2,94} = 2.65$, $p = 0.08$).

Post-hoc analyses indicated that both Resistance Training and Agility Training had significantly reduced fall risk scores compared with the Stretching group at the end of the intervention period. PPA fall risk scores were reduced by 57% and 48% in the Resistance and Agility Training groups respectively,

compared with 20% in the stretching group. In both the Resistance and Agility Training groups, the reduction in fall risk was mediated primarily by improved postural stability, where sway was reduced by 31% and 29% respectively. In contrast, sway did not change in the Stretching group (0.0%)

The Agility and Resistance training groups showed continued improvements in fall risk throughout the intervention period (Figure 9). The repeated measure MANOVA analysis indicated a significant linear contrast ($p < 0.001$) and an insignificant quadratic contrast ($p = 0.15$) for change in fall risk in the Resistance Training group. In the Agility Training group, there were significant linear ($p < 0.001$) and quadratic contrasts ($p < 0.05$), indicating that improvement beyond the mid-point of the trial was less marked.

### 6.3.3 Changes in Squat Load and Sway in the Resistance Training Group

Over the trial period, squat load normalized to body mass (load (kg)/mass (kg)) used in the exercise regime for the Resistance Training group increased by 16% (SD = 5.2). Increases in squat load were significantly associated with reductions in postural sway scores ($r = -0.45$, $p < 0.01$).

### 6.3.4 Adverse Events

Musculoskeletal complaints (e.g., sore neck, gluteal tendinopathy) developed in 10 women in the Resistance Training group, three in the Agility Training group, and two in the Stretching group. All musculoskeletal complaints either resolved or diminished within 3 weeks of onset and none required a physician's attention. Four participants in the Agility Training group experienced shortness of breath that required them to desist from participating for 5 minutes before continuing. There were two trips (one participant) and six falls (four participants) in the Agility Training group. None of the falls in this class resulted in injuries requiring medical attention. There was one fall on the first day in the Resistance Training group (participant slid off the seat and landed on the floor with her sacrum) that required medical attention (X-ray). Although no fracture was sustained and this individual recovered within four weeks, she then developed symptoms of polymyositis and withdrew from the study.

### 6.3.5 Falls

Based on the fall diaries, which excluded falls that occurred in classes, there were 18 falls in the Resistance Training group (one subject fell seven times), 11 falls in the Agility Training group, and 10 falls in the Stretching group during the 25-week intervention period. There were 10 frequent fallers, defined as women having more than one fall during the intervention period; three in the Resistance Training group, five in the Agility Training group and two in the Stretching group.

Table 16. Descriptive statistics for descriptor variables (N = 98).

| Variable* | Resistance (n = 32) Mean (SD) | Agility (n = 34) Mean (SD) | Stretching (n = 32) Mean (SD) |
|---|---|---|---|
| Age (yr) | 79.6 (2.1) | 78.9 (2.8) | 79.5 (3.2) |
| Height (cm) | 160.1 (6.0) | 157.0 (6.1) | 158.3 (8.4) |
| Mass (kg) | 59.9 (9.4) | 62.5 (9.3) | 65.2 (12.6) |
| Prescribed Medications | 2.6 (2.3) | 3.2 (2.1) | 4.1 (3.3) |
| High Contrast Acuity[†] | 1.5 (0.9) | 2.4 (4.4) | 1.5 (0.6) |
| Low Contrast Acuity[†] | 2.6 (1.6) | 3.8 (4.7) | 2.9 (1.3) |
| Tactile Sensitivity[‡] | 4.4 (0.5) | 4.3 (0.5) | 4.1 (0.6) |
| MMSE Score (max 30 points) | 28.7 (1.4) | 28.6 (1.4) | 28.3 (1.9) |
| Number of Classes Attended | 41.0 (9.4) | 41.9 (6.1 | 37.8 (10.1) |
| Baseline PASE | 98.0 (51.8) | 83.3 (35.1) | 76.3 (30.0) |
| Fall in Last 4 Weeks[§] | 5 (15.6) | 1 (2.9) | 2 (6.3) |
| Osteoarthritis[§] | 11 (34.4) | 13 (38.2) | 17 (53.1) |
| Osteoarthritis of the Knee[§] | 5 (15.6) | 6 (17.6) | 6 (18.8) |
| Use of Walking Aid[§] | 4 (12.5) | 2 (5.9) | 5 (15.6) |

*There were no significant differences among the groups for any variable.
†Measured in terms of the minimum angle resolvable in minutes of arc.
‡Measured in logarithms of milligrams pressure.
§Count (%). Count = Number of "yes" cases within each group. % = Percent of "yes" cases within each group.

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Table 17. Mean values (SDs) for the outcome measures – Baseline, midpoint, and final (N = 98).

| Variable* | Baseline Mean (SD) | Midpoint Mean (SD) | Final Mean (SD) |
|---|---|---|---|
| *Resistance (n = 32)* | | | |
| Fall Risk Score | 2.22 (0.70) | 1.39 (0.98) | 0.95 (1.01)‡ |
| Postural Stability (mm) | 230.1 (93.1) | 183.6 (123.2) | 159.6 (82.0)§ |
| Quadriceps Strength (kg) | 17.2 (7.2) | 20.4 (8.4) | 18.9 (8.6) |
| Hand Reaction Time (msec) | 328.3 (44.3) | 284.1 (49.3) | 267.8 (52.3) |
| Proprioception (deg) | 2.2 (2.1) | 1.9 (1.0) | 1.5 (1.2) |
| Edge Contrast (dB) | 17.8 (2.1) | 19.3 (2.0) | 19.2 (2.2) |
| Dorsiflexion Strength (kg) | 6.4 (2.2) | 7.3 (2.6) | 7.6 (2.5) |
| Foot Reaction Time (msec) | 380.5 (81.6) | 320.1 (41.6) | 331.2 (63.9) |
| CB&M Scale (max 85 points) | 44.6 (21.6) | 49.5 (20.7) | 51.2 (21.9) |
| *Agility (n = 34)* | | | |
| Fall Risk Score | 2.40 (0.86) | 1.49 (0.97) | 1.26 (0.93)‡ |
| Postural Stability | 219.2 (80.3) | 179.5 (98.1) | 155.3 (91.1)§ |
| Quadriceps Strength | 17.0 (6.5) | 19.9 (6.2) | 17.2 (7.9) |
| Hand Reaction Time | 337.8 (61.4) | 298.6 (53.6) | 294.9 (55.1) |
| Proprioception | 1.8 (1.2) | 1.8 (1.6) | 1.5 (1.2) |
| Edge Contrast | 17.3 (2.3) | 18.9 (2.1) | 18.7 (2.7) |
| Dorsiflexion Strength | 5.1 (2.6) | 7.3 (1.9) | 6.8 (2.9) |
| Foot Reaction Time | 379.0 (67.8) | 340.2 (68.1) | 353.9 (61.6) |
| CB&M Scale | 39.9 (17.5) | 51.5 (15.5)† | 48.9 (16.4) |
| *Stretching (n = 32)* | | | |
| Fall Risk Score | 1.92 (0.83) | 1.50 (0.95) | 1.53 (1.21) |
| Postural Stability | 217.0 (104.7) | 196.6 (122.9) | 217.3 (148.2) |
| Quadriceps Strength | 16.1 (7.2) | 19.2 (7.2) | 17.5 (6.4) |
| Hand Reaction Time | 307.6 (43.1) | 290.5 (49.1) | 280.7 (60.2) |
| Proprioception | 1.7 (0.9) | 2.0 (1.6) | 1.8 (1.2) |
| Edge Contrast | 18.0 (1.5) | 18.8 (1.8) | 18.6 (1.9) |
| Dorsiflexion Strength | 5.4 (2.9) | 6.4 (2.8) | 6.3 (2.4) |

| Variable* | Baseline Mean (SD) | Midpoint Mean (SD) | Final Mean (SD) |
|---|---|---|---|
| Foot Reaction Time | 362.8 (57.6) | 332.3 (49.8) | 345.2 (57.5) |
| CB&M Scale | 40.4 (18.3) | 45.8 (17.8) | 45.0 (17.4) |

*High fall risk scores, high stability (sway) values, high reaction time values, low quadriceps strength values, and low edge contrast scores indicate impaired performances. For the CB&M Scale (Community Balance and Mobility Scale), a higher score indicates better physical function.
†Significantly different from the Resistance Training and the Stretching group at $p < 0.05$.
‡Significantly different from the Stretching group, $p < 0.01$.
§Significantly different from the Stretching group, $p \leq 0.05$.
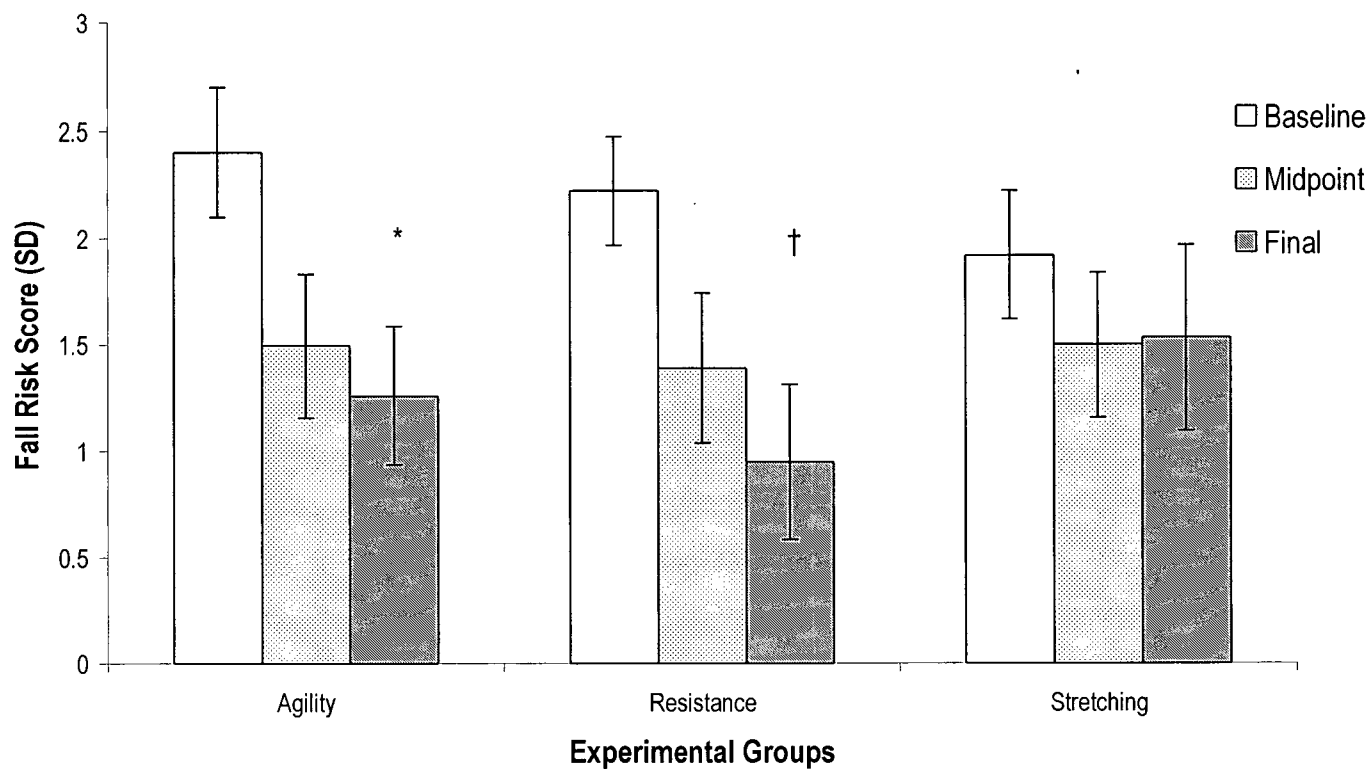
Figure 9. Fall risk score.
*Significantly different from the Stretching group, p = 0.005.
†Significantly different from the Stretching group, p = 0.001.
Error bars represent 95% confidence intervals.

## 6.4 Discussion

This study found that both high-intensity resistance training and agility training were effective in reducing fall risk compared with a stretching program in older community-dwelling women with low bone mass. After 25 weeks of intervention, Resistance Training and Agility Training significantly reduced the fall risk score by 57% and 48%, respectively, compared with a 20% reduction as a result of Stretching exercises. Based on normative data from the Randwick Falls and Fractures Study (66), these changes represent a reduction in the risk of falling over 12 months from over 80% to 50-55%.

Of the five components that contribute to the calculation of the fall risk score, it was hypothesized that postural stability, quadriceps strength, and hand reaction time would be amenable to change by the intervention programs. Both Resistance Training and Agility Training significantly improved postural stability compared with Stretching exercises, but that the groups did not differ significantly in the tests of strength and reaction time at the end of the trial. This indicates that for both groups the reduction in fall risk scores was primarily mediated via improved postural stability.

The finding that the novel Agility Training improved postural stability is consistent with previous investigations of other types of balance training in other populations of older people (10,358,359). However, the finding that Resistance Training improved postural stability contrasts with some previous studies (63,80). The inconsistencies in the findings here may relate to differences in the intensity of the resistance training programs used across studies. For example, the current study and the study by Nelson et al. (62) used high-intensity resistance training programs -- 75 to 85% of 1RM, two sets of six to eight repetitions; and 85% of 1RM, three sets of eight repetitions respectively. In contrast, studies with lower intensity interventions such as 70 to 75% of 1RM, two sets of 13 repetition maximum (63), or home-based lower extremity resistance training program using therabands or body mass (80) have not been found to improve balance.

The Resistance Training group significantly increased the squat load used in the exercise program. However, this was not reflected by parallel improvements in the seated isometric knee extension test. The

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lack of significant improvement in the strength outcome measure may reflect the specificity of training (standing squats) that differed from the conditions for testing (seated knee extension). The lack of generalization across strength measures has also been reported by Murphy and Wilson (360), who found that in athletes who trained with standing squats, significant strength gains were demonstrated in a 1 RM standing squat test but not in a seated knee extension test. Increases in squat load were significantly associated with reductions in sway scores on the compliant foam rubber mat, and this interesting association may indicate how resistance training is related to improved postural stability and reduced fall risk.

It has been postulated that regular exercise may maintain the reactive capacity of older people by delaying the deterioration of the dopamine systems, enhancing integrity of cerebral circulation, and having trophic influence on neurons that supply muscle fibers (361). There were strong trends that indicated that the agility and resistance training groups had faster reaction times at the end of the trial for both a finger and foot-press response, but these differences did not reach statistical significance. Significant improvements may have been evident with a longer duration of the intervention period or with increased power with a slightly larger sample (10).

At the study mid-point (13 weeks), there were few differences among the groups. However, for both the Resistance and Agility groups further improvements occurred in the second period of the trial, so that significant differences were apparent for the fall risk and postural sway measures. This would indicate that trials of six-month duration or more are necessary to maximize beneficial intervention effects.

Improvement in general balance and mobility (CB&M scores) was apparent in the Agility Training group at 13 weeks, but the relative improvement over the other groups was not maintained at the study endpoint. This may be due to the lack of both established protocols and an appropriate safe environment for progressing an agility training program, compared with a resistance training program. Further, all three groups showed improvements in this measure at the end of the trial, which may reflect direct participation in

the programs, indirect activity associated with attending the classes and increased activity outside the program as indicated by the changes in PASE scores.

It appeared that the Agility Training program carried a higher risk of falls compared with the Resistance Training. The Agility Training program required considerable planning, many safety precautions, and a higher ratio of instructor to participant. Furthermore, there is no clinical or research template by which to progress the agility training program, unlike the resistance training program. Although there were a greater number of adverse effects in the Resistance Training group than in the Agility Training group, the short-term musculoskeletal complaints were mild and self-limiting. Thus, I would consider that a group-based agility program is more complex to deliver outside of the research setting than a resistance training program. On the other hand, it was clear to me (from observation) that the Agility Training participants found the program particularly enjoyable, and this may enhance long-term compliance.

## 6.5 Limitations

This study has certain limitations. First, the interventions were staff-intensive and their availability in the health system may be limited by cost. Second, the primary study outcome was fall risk, not falls. Thus, future research using falls as the primary outcome measure is needed to confirm the role of resistance training and agility training in fall prevention in those with low bone mass. It would be also be useful to contrast the effects of these interventions against proven exercise-based (76,95,107-109,112) and non-exercised based fall prevention (111) interventions.

## 6.6 Summary and Future Directions

In conclusion, this present study demonstrated that both high-intensity resistance training and agility training significantly reduced fall risk in older women with low bone mass compared with a stretching program. Furthermore, this study demonstrated that this population has the capacity to participate in demanding exercise programs with minimal risk. These exercise programs may have particular public health benefits as it has been shown that older women with low bone mass may be at increased risk of

falling (see Chapter Five) as well as sustaining fall-related fractures. However, future studies powered to

measure falls are needed to determine if both types of exercise programs reduce falls.

## Chapter Seven: Part Four

### 7.1 Introduction[5]

Osteoporotic fractures constitute a major health care problem worldwide. As 90% of all hip fractures are secondary to falls (7), effective fracture prevention requires both fall risk reduction and bone health promotion. Evidence from randomized controlled trials suggests that exercise has the potential to positively augment both domains of fracture risk (10,12,62). The previous chapter described a randomized controlled trial of exercise in 75 to 85 year old women and this chapter reports the bone outcome measures from that study.

Few randomized controlled trials of exercise intervention on bone health have targeted women over the age of 75. Also, a major limitation of previous exercise studies on bone health in older adults is the lack of information on possible bone structural changes that may occur with exercise. In both bone research and clinical practice, the current choice to evaluate bone health is most commonly dual energy X-ray absorptiometry (DXA). Although there are many advantages to using DXA (e.g., its precision and the ability to predict fracture risk), it measures only two-dimensions of bone. As bone's mechanical integrity is determined by both its material and *structural* properties (130), both these dimensions should be evaluated in studies of exercise and bone health in older adults. DXA can not directly measure structural changes in bone. Thus, it has been recommended that DXA measurements be complemented by other methods, such as peripheral quantitative computed tomography (pQCT), to provide information on changes in bone structure (175). Otherwise, effects of exercise on bone may be underestimated (175).

Therefore, the primary purpose of this study was to compare the effects of two types of group-based exercise programs (high-intensity resistance training and agility training) on bone health, as measured by both DXA and the novel measure of bone structure -- pQCT, in community-dwelling older

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[5] A version of this chapter has been submitted for publication. Liu-Ambrose T, Khan KM, Eng JJ, McKay HA. Cortical bone density increases with bone resistance and agility training: A six-month randomized controlled trial. Submitted to Journal of Gerontology, January 2004.

women with low bone mass. This is the first study to elucidate the influence of exercise on bone health in women 75 years or older with low bone mass.

## 7.2 Methods

### 7.2.1 Study Design

The study design was described in Chapter Six, Section 6.2.1.

### 7.2.2 Participants

The sample comprised women aged 75 to 85 years old who participated in the randomized, controlled prospective study of three different types of group-based exercise programs (resistance training, agility training, and general stretching) described in Chapter Six. All women had osteoporosis or osteopenia diagnosed by DXA (defined as a T-score at the total hip or spine at least 1.0 standard deviations below the young normal sex-matched areal bone mineral density of the Lunar reference database) (310).

### 7.2.3 Measurements

7.2.3.1 Descriptive Variables

**Anthropometry**

Standing height was measured to the nearest millimetre using a wall-mounted stadiometer, and body mass was measured with an electronic scale to the nearest 0.1 kilograms. For both height and mass, I used the mean of two values or the median of three values for analysis.

Body composition estimates of bone mineral free lean mass and fat mass were generated from DXA total body scans. Precision of our laboratory's bone densitometer, in vivo, $0.30 \pm 0.15\%$ CV for total body lean mass and $1.42 \pm 0.78\%$ CV for total body fat mass.

**Questionnaires**

General health was assessed with questions from the Canadian Multicentre Osteoporosis Study (CaMOS) questionnaire (349) that relate to reproductive history, fracture and fall history, current medication use (including bisphosphonates for osteoporosis/osteopenia), current supplement use, the presence of

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medical conditions known to influence bone health (e.g., hypothyroidism). This questionnaire was administered at baseline by trained interviewers. As well, all participants underwent a physician assessment (Dr. Lynda Thayer) to confirm current health status and health history. Use of a walking aid was also recorded.

Cognitive state was assessed using the Mini-Mental State Examination (MMSE) (348). Each participant's current level of physical activity was determined at all three measurement periods (Figure 7, Chapter Six) with the Physical Activities Scale for the Elderly (PASE) questionnaire (353,354).

7.2.3.2 Bone Outcome Measures

Bone measurements were performed at baseline and trial completion only (i.e., not at the 13-week midpoint).

**Peripheral Quantitative Computed Tomography**

Peripheral QCT measurements were performed at the tibia and radius using the Norland/Stratec XCT 540 bone scanner (Stratec Medizintechnic GmbH, Pforzheim, Germany). Together with my co-supervisor Dr. Heather McKay, I developed the pQCT acquisition protocol for this population. As pQCT is a novel research technique, protocols are not yet "standardized" as they are for DXA measurements. I then supervised the training and quality control assessment of three measurement technicians. A single 2.2 mm slice was taken on the left lower leg at the 50% site (50% of the tibial length proximal to the distal endplate of the tibia) and at the 10% site. A single 2.2 mm slice was also taken at the left forearm at the 30% site (30% of the ulna length proximal to the distal endplate of the radius) and at the 10% site. I used a voxel size of 0.5 mm. A 30 mm planar scout view over the joint line of interest was performed to define the anatomic reference line. The relative location of the subsequent slice was automatically adjusted to this reference. The variables used for analysis at the shaft regions (50% site of lower leg and 30% of the site of the forearm) were: cortical bone content (mg/mm), cortical bone cross-sectional area ($mm^2$), cortical bone volumetric density ($mg/cm^3$), and the polar stress/strain index (density-weighted polar section modulus; SSI in $mm^3$). The variables used for analysis at the distal sites (10% site) were: total bone content (mg/mm),

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total bone cross-sectional area (mm$^2$), and total bone volumetric density (mg/cm$^3$). In our laboratory, the pQCT precision (with repositioning), in vivo, varies from 0.40 to 1.85% CV. Without repositioning, the precision varies from 0.20 to 1.83%.

I analyzed all the scans by developing an analysis mask for each site and applying it to all the scans of that site. In consultation with Dr. McKay, the specifications of each mask were determined by considering the following factors: the scan profiles (Figure 10), the success rate of analysis (i.e., the number of scans successfully analyzed by the specific mask), and the recommendations of our laboratory's industry-based pQCT consultant. Different tissues within each slice were separated according to different density thresholds. Those areas with density values above 710 mg/cm$^3$ were considered to be cortical bone and areas with density values between 400 mg/cm$^3$ and 200 mg/cm$^3$ were considered to be trabecular bone. The following analysis mask was used for the 50% site of the tibia, 30% and 10% sites of the radius:

CALCBD (total and trabecular bone)

Outer Threshold = 710 mg/cm$^3$

Inner Threshold = 710 mg/cm$^3$ [6]

Contour Mode = 1 (filter on)

Peel Mode = 2

CORTBD (cortical bone)

Threshold = 710 mg/cm$^3$

Cortical Mode = 1

The specific analysis mask analysis mask used for the 10% site of the tibia was:

CALCBD (total and trabecular bone)

Outer Threshold = 200 mg/cm$^3$

Inner Threshold = 400 mg/cm$^3$

Contour Mode = 3 (filter on)

Peel Mode = 2

CORTBD (cortical bone)

Threshold = 169 mg/cm$^3$

Cortical Mode = 1

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[6] This threshold does not influence the cortical bone results.

Name
CT No.
Birth

Object length : 225.0 mm   female
Scan date : 02-19-2002 Age : 79

PROFILE

10 mm    0.500 mm

18.449
3 RAD30

Density [mg/ccm]

Distance [mm]

CR=Start/End; ESC=CANCEL; TAB=Dir. F4=Save F2=Scale max. F3=draft

INFO    STANDARD    DISTANCE    PROFILE    OK
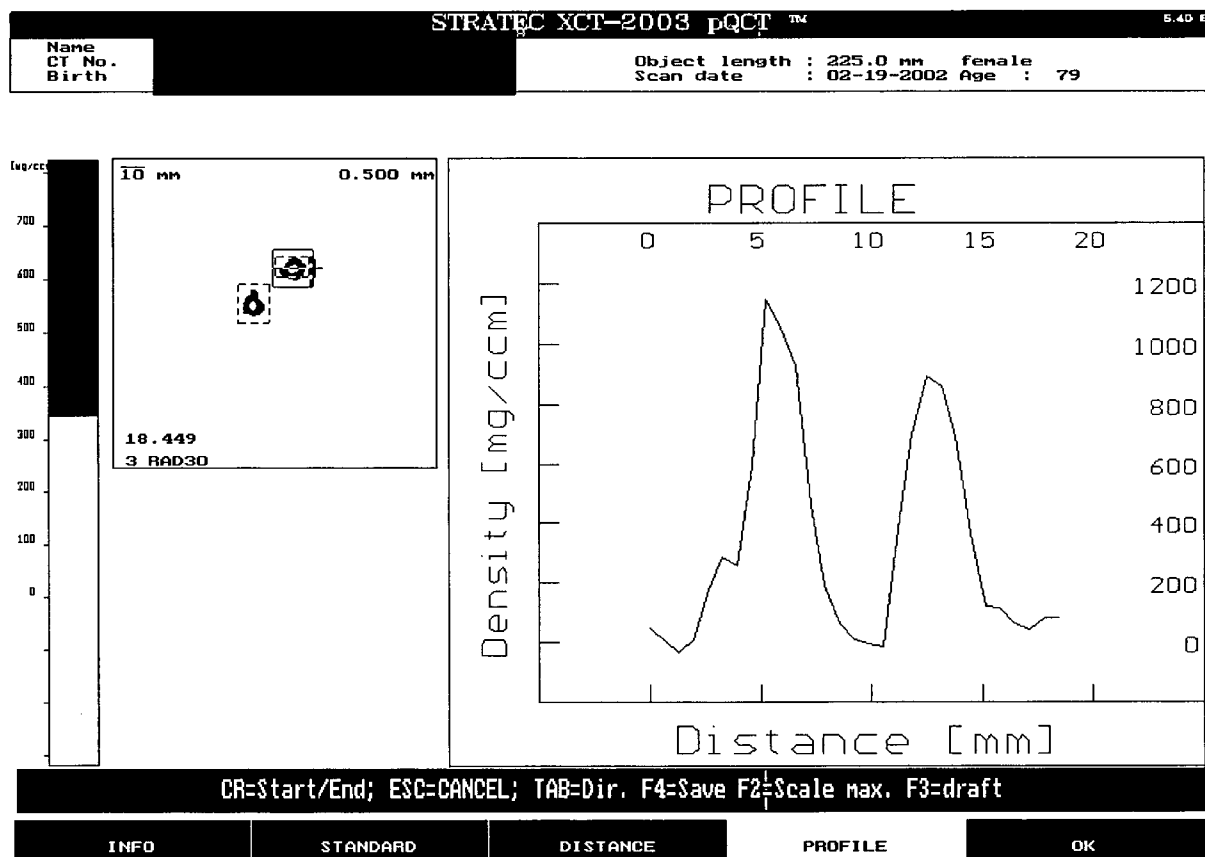
Figure 10. Scan profile of the 30% site of the radius.

## Bone Densitometry

Areal bone mineral density (BMD, g/cm$^2$) was assessed at the proximal femur using a Hologic

4500 DXA (Hologic Inc., Waltham, Massachusetts, USA). The total hip, femoral neck and trochanteric sub-

region were analyzed.

The total radiation exposure per session was less than 10 millirem, which is similar to the

background radiation one would receive making a one-way flight from Vancouver to Halifax on a

commercial airline. The participants wore clothing without metal (e.g., zippers) and removed jewellery for

the measurements. DXA is the method of choice for measuring areal BMD and the precision, in vivo, in our

laboratory is better than 1.2% (CV) for areal BMD at all sites. A spine and anthropomorphic phantom were

scanned each day of assessment to maintain quality assurance. I performed and analyzed all the DXA

scans using standard Hologic analysis protocol (362).

Table 18. Lumar spine in vitro precision (% CV) for the Hologic QDR 4500 densitometer over two data collection periods.

|  | February 2002 | August 2002 |
| --- | --- | --- |
| Bone Area (cm$^2$) | 0.294 | 0.343 |
| Bone Mineral Content (g) | 0.592 | 0.525 |
| Areal BMD (g/cm$^2$) | 0.468 | 0.394 |

### 7.2.3.3 Compliance

Adherence with the assigned exercise program was recorded for each participant and compliance is expressed as the percentage of the 48 classes (maximum number of classes) attended as described in Chapter Six, Section 6.2.3.5.

### 7.2.4 Randomization

After baseline measurement, participants were randomly assigned (by random draw) to one of three groups: Resistance Training, Agility Training, and Stretching (sham exercise). Randomization was stratified by baseline postural stability (for fall risk) as well as baseline total hip areal BMD and the use of bisphosphonates (yes/no).

### 7.2.5 Sample Size

The required sample size for this study was based on change predictions of 1% for the Agility Training group, 0% for the Resistance Training group, and –1% for the Stretching group in cortical area at the tibial shaft as assessed by pQCT. Change in cortical area was assumed to be the least responsive variable across all outcome measures of this randomized controlled trial. Assuming a 30% attrition rate and using an alpha level of $\leq 0.05$, recruiting 30 participants per group would provide a power of greater than 80% to detect a 1% difference between groups.

### 7.2.6 Exercise Intervention

The exercise intervention began one week after baseline measures were completed and participants were required to attend their assigned exercise class twice weekly. The exercise intervention is detailed in Chapter Six, Section 6.2.6.

### 7.2.7 Adverse Events

After each exercise session, participants were questioned about the presence of any adverse effects, such as musculoskeletal pain or discomfort. Modifications in the training program were made on an individual basis as necessary. Any falls that occurred during the classes were recorded. All instructors also monitored participants for symptoms of angina and shortness of breath.

### 7.2.8 Statistical Analysis

The data were analysed on an intention to treat basis, using SPSS (Windows Version 11.0) statistical software. Data were checked with scatterplots to eliminate errors and outliers (greater than 3 SD above or below the mean). Dependent variables were checked for normality by calculating skewness and kurtosis. If the ratio of each statistic to its standard error is less than 2 or greater than –2, this indicates a normal population distribution (333). Comparisons of group characteristics and baseline scores were undertaken using a Chi Square test for differences in proportions and analysis of variance (ANOVA) for differences in means. Changes in bone outcome measures at trial completion were compared by analysis of covariance (ANCOVA) with baseline body mass (kg), change in body mass (kg), and the use of bisphosphonates (yes/no) entered as covariates. Post hoc analyses were then performed where there were significant main effects with the overall alpha error level of $\leq 0.05$ reduced to $\leq 0.03$.

Sub-analyses were performed to compare the general trend in bone outcome measures at trial completion between individuals not prescribed bisphosphonates (n = 32) and those who were prescribed these medications (n = 66). Baseline body mass and changes in body mass were entered as covariates in these sub-analyses.

### 7.3 Results

### 7.3.1 Descriptive Variables, Exercise Compliance, and Physical Activity Levels

The mean age of the cohort was 79 ± 3 years. The three groups did not differ in any of the descriptive variables at baseline (Table 19). There was no significant difference in change in body mass, standing height, lean mass, or fat mass among the three groups. In the entire study cohort, compliance to

the exercise classes was 83%. The Resistance Training group had an average compliance of 85%, the Agility Training group 87%, and the Stretching group 79%.

Physical activity levels (PASE scores) increased during the 25-week intervention period within all three groups ($p < 0.001$). However, these changes did not differ significantly among the groups ($p = 0.80$), and changes in PASE scores were not significantly related with changes in bone ($r \leq 0.17$, $p \geq 0.11$).

### 7.3.2 Bone Outcome Measures

There were no significant differences among the groups in any of the bone outcome measures at baseline (Table 20). Table 21 provides the 25-week mean change in the bone outcome measures for the three study groups. At trial completion, there were no significant differences among the groups in the DXA outcome measures. The ANCOVA model revealed a significant difference in cortical bone density among the groups at the 50% site of the left tibia and at the 30% site of the left radius. Post-hoc analyses showed that the Agility Training group significantly increased cortical bone density by pQCT at the 50% site of the tibia compared with the Stretching group (Figure 11) and the Resistance Training group significantly increased cortical bone density at the 30% site of the radius compared with the Agility Training group (Figure 12). Specifically, cortical bone density significantly increased by 0.5% in the Agility Training group compared with a 0.4% loss in the Stretching group at the 50% site of the tibia, while cortical bone density significantly increased by 1.4% in the Resistance Training group compared with a 0.4% loss in the Agility Training group at the 30% site of the radius.

Similar trends in bone changes were observed whether participants were taking bisphosphonates medication or not. For example, in both the non-bisphosphonate only and the bisphosphonates only sub-analyses, those in the Agility Training group demonstrated the greatest gain in cortical volumetric density while those in the Stretching group demonstrated the greatest loss at the 50% site of the tibia. Furthermore, those in the Resistance Training group demonstrated the greatest gain in density at the 30% site of the radius in the sub-analyses.

### 7.3.3 Adverse Events

Musculoskeletal complaints (e.g., sore neck, gluteal tendinopathy) developed in 10 women in the Resistance Training group, three in the Agility Training group, and two in the Stretching group. All musculoskeletal complaints either resolved or diminished within 3 weeks of onset and none required a physician's attention.

Table 19. Descriptive statistics for descriptor variables (N = 98).

| Variable* | Resistance (n = 32) Mean (SD) | Agility (n = 34) Mean (SD) | Stretching (n = 32) Mean (SD) |
|---|---|---|---|
| Age (yr) | 79.6 (2.1) | 78.9 (2.8) | 79.5 (3.2) |
| Baseline Height (cm) | 160.1 (6.0) | 157.0 (6.1) | 158.3 (8.4) |
| Change in Height (cm) | -0.2 (2.0) | -0.1 (0.6) | 0.1 (0.64) |
| Baseline Body Mass (kg) | 59.9 (9.4) | 62.5 (9.3) | 65.2 (12.6) |
| Change in Body Mass (kg) | -1.2 (3.6) | -1.0 (2.1) | -1.0 (2.0) |
| Lean Mass (g) | 37990.9 (4061.7) | 38084.3 (4543.2) | 39681.6 (5354.8) |
| Change in Lean Mass (g) | 377.3 (1124.6) | 318.6 (1046.9) | 303.2 (1050.3) |
| Fat Mass (g) | 20558.2 (5694.8) | 23939.1 (6275.8) | 24512.0 (8449.0) |
| Change in Fat Mass (g) | -148.8 (1298.0) | -529.4 (1490.5) | -356.2 (1433.7) |
| Number of Prescribed Medications | 2.6 (2.3) | 3.2 (2.1) | 4.1 (3.3) |
| Daily Dose of Calcium Supplement (mg) | 1164.3 (529.7) | 926.3 (460.1) | 750.0 (312.6) |
| Daily Dose of Vitamin D Supplement (IU) | 892.9 (265.2) | 780.0 (303.3) | 638.9 (404.3) |
| Years Since Menopause | 29.8 (5.0) | 30.3 (6.5) | 29.7 (6.3) |
| MMSE Score (max 30 points) | 28.7 (1.4) | 28.6 (1.4) | 28.3 (1.9) |
| Number of Classes Attended | 41.0 (9.4) | 41.9 (6.1 | 37.8 (10.1) |
| Baseline PASE Score | 98.0 (51.8) | 83.3 (35.1) | 76.3 (30.0) |
| Change in PASE Score | 1.2 (41.0) | 16.9 (45.2) | 19.1 (40.7) |
| Current Bisphosphonate Use[†] | 21 (65.6) | 23 (67.6) | 22 (70.1) |
| Estrogen Replacement Therapy[†‡] | 4 (12.5) | 5 (14.7) | 4 (12.9) |
| Daily Calcium Supplement[†] | 13 (40.6) | 17 (50.0) | 18 (58.0) |
| Daily Vitamin D Supplement[†] | 14 (29.4) | 10 (43.8) | 14 (45.2) |
| Both Calcium and Vitamin D Supplement[†] | 11 (34.4) | 9 (26.5) | 13 (40.6) |
| History of Fragility Fracture[†§] | 22 (68.8) | 20 (58.8) | 24 (75.0) |
| History of Smoking[†§] | 13 (40.6) | 20 (58.8) | 11 (34.4) |
| Smoking Currently[†] | 3 (9.4) | 1 (2.9) | 1 (3.1) |

*No significant differences among the groups for any variable. Change calculated as final value minus baseline value.
†Count (%). Count = Number of "yes" cases within each group. % = Percent of "yes" cases within each group.
‡In the last 5 years.
§In lifetime.

Table 20. Mean (SDs) baseline values.

| Variable* | Resistance<br>Mean (SD) | Agility<br>Mean (SD) | Stretching<br>Mean (SD) | p-Value |
|---|---|---|---|---|
| *DXA* | *n = 29†* | *n = 33* | *N = 32* | |
| Total Hip BMD (g/cm²) | 0.67 (0.14) | 0.69 (0.11) | 0.69 (0.12) | 0.763 |
| Femoral Neck BMD (g/cm²) | 0.58 (0.11) | 0.60 (0.08) | 0.59 (0.10) | 0.708 |
| Trochanter BMD (g/cm²) | 0.51 (0.11) | 0.53 (0.08) | 0.52 (0.09) | 0.872 |
| *pQCT at 50% Tibia* | *n = 32* | *n = 34* | *N = 31* | |
| Cortical Content (mg/mm) | 214.11 (68.83) | 229.70 (51.83) | 219.93 (47.18) | 0.530 |
| Cortical Area (mm²) | 198.21 (56.65) | 212.39 (42.92) | 205.46 (40.74) | 0.479 |
| Cortical Density (mg/cm³) | 1069.04 (48.01) | 1076.20 (42.26) | 1067.24 (42.39) | 0.687 |
| SSI (mm³) | 1260.37 (348.00) | 1338.39 (270.22) | 1361.40 (310.47) | 0.400 |
| *pQCT at 10% Tibia* | *n = 32* | *n = 34* | *N = 31* | |
| Total Content (mg/mm) | 160.11 (37.72) | 165.75 (29.37) | 161.79 (29.15) | 0.766 |
| Total Area (mm²) | 537.12 (79.69) | 548.68 (77.84) | 586.41 (147.56) | 0.160 |
| Total Density (mg/cm³) | 304.26 (81.84) | 307.22 (67.82) | 287.14 (72.66) | 0.510 |
| *pQCT at 30% Radius* | *n = 22* | *n = 33* | *N = 25* | |
| Cortical Content (mg/mm) | 57.64 (18.59) | 59.05 (11.71) | 55.66 (13.47) | 0.677 |
| Cortical Area (mm²) | 51.78 (14.01) | 52.83 (9.62) | 50.62 (10.43) | 0.760 |
| Cortical Density (mg/cm³) | 1096.80 (76.55) | 1114.59 (32.56) | 1092.10 (52.85) | 0.249 |
| SSI (mm³) | 153.94 (45.78) | 159.86 (32.64) | 154.42 (36.45) | 0.804 |
| *pQCT at 10% Radius* | *n = 29* | *n = 33* | *N = 29* | |
| Total Content (mg/mm) | 57.07 (17.87) | 58.39 (14.37) | 51.56 (15.69) | 0.219 |
| Total Area (mm²) | 120.22 (31.27) | 127.31 (32.12) | 112.13 (39.98) | 0.231 |
| Total Density (mg/cm³) | 478.02 (85.77) | 469.39 (91.44) | 481.82 (108.02) | 0.870 |

*There were no significant differences among the groups for any measure.
†Differences in number of participants between DXA and pQCT data and with pQCT data are due to rejection of scans during analysis, technical difficulties, or participants declining to undertake scans.

Table 21. Mean change (95% CI).

| Variable | Resistance<br>Mean Δ (95% CI)* | Agility<br>Mean Δ (95% CI) | Stretching<br>Mean Δ (95% CI) | p-Value |
|---|---|---|---|---|
| *DXA* | *N = 29†* | *n = 33* | *n = 31* | |
| Total Hip BMD (g/cm$^2$) | .001 (-0.006, 0.009) | 0.006 (0.000, 0.013) | 0.003 (-0.004, 0.010) | 0.576 |
| Femoral Neck BMD (g/cm$^2$) | -0.002 (-0.009, 0.005) | 0.004 (-0.003, 0.011) | -0.001 (-0.007, 0.006) | 0.348 |
| Trochanter BMD (g/cm$^2$) | 0.010 (-0.004, 0.023) | 0.008 (-0.005, 0.020) | 0.002 (-0.011, 0.015) | 0.709 |
| *pQCT at 50% Tibia* | *n = 32* | *n = 33* | *n = 30* | |
| Cortical Content (mg/mm) | -1.08 (-3.40, 1.24) | -1.22 (-3.46, 1.04) | -2.78 (-5.17, -0.39) | 0.538 |
| Cortical Area (mm$^2$) | -1.05 (-3.40, -1.29) | -2.18 (-4.46, 0.09) | -1.84 (-4.26, 0.58) | 0.784 |
| Cortical Density (mg/cm$^3$) | -0.06 (-5.49, 5.38) | 5.32 (0.04, 10.59)‡ | -4.99 (-10.60, 0.62) | 0.033 |
| SSI (mm$^3$) | -13.67 (-34.83, 7.49) | -8.37 (-28.93, 12.19) | -21.95 (-43.80, -0.10) | 0.667 |
| *pQCT at 10% Tibia* | *n = 31* | *n = 32* | *n = 28* | |
| Total Content (mg/mm) | -0.45 (-1.75, 0.84) | -0.97 (-2.23, 0.28) | -0.24 (-1.60, 1.13) | 0.713 |
| Total Area (mm$^2$) | 1.60 (-4.98, 8.17) | -3.76 (-10.12, 2.60) | 2.81 (-4.11, 9.74) | 0.323 |
| Total Density (mg/cm$^3$) | -2.24 (-6.80, 2.32) | 0.16 (-4.26, 4.58) | -2.93 (-7.74, 1.88) | 0.602 |
| *pQCT at 30% Radius* | *n = 21* | *n = 31* | *n = 23* | |
| Cortical Content (mg/mm) | 1.00 (-0.66, 2.67) | -0.71 (-2.04, 0.63) | -0.67 (-2.25, 0.91) | 0.240 |
| Cortical Area (mm$^2$) | 0.45 (-0.91,1.80) | -0.41 (-1.50, 0.68) | -0.46 (-1.74, 0.83) | 0.559 |
| Cortical Density (mg/cm$^3$) | 15.39 (2.27, 28.50)§ | -4.55 (-15.07, 5.97) | -3.54 (-15.98, 8.89) | 0.050 |
| SSI (mm$^3$) | 4.95 (-1.50, 11.39) | -0.60 (-5.77, 4.57) | -1.00 (-7.11, 5.11) | 0.337 |
| *pQCT at 10% Radius* | *n = 27* | *n = 32* | *n = 28* | |

| Variable | Resistance | Agility | Stretching | p-Value |
| --- | --- | --- | --- | --- |
| | Mean Δ (95% CI)* | Mean Δ (95% CI) | Mean Δ (95% CI) | |
| Total Content (mg/mm) | 0.99 (-2.57, 4.65) | -3.32 (-6.68, 0.04) | 1.85 (-1.77, 5.47) | 0.085 |
| Total Area (mm²) | 3.04 (-9.90, 15.98) | -6.36 (-18.24, 5.51) | 7.18 (-5.62, 19.98) | 0.287 |
| Total Density (mg/cm³) | -2.75 (-36.79, 1.28) | 3.62 (-27.60, 34.84) | -8.75 (-42.41, 24.91) | 0.867 |

*Δ = Change calculated as final value minus baseline value. Mean change values adjusted by baseline body mass (kg), change in body mass (kg), and the current use of bisphosphonates (yes/no).

†Differences in number of participants between DXA and pQCT data and with pQCT data are due to rejection of scans during analysis, technical difficulties, or participant declining to undertake scans.

‡Significantly different from the Stretching group at p = 0.02.

§Significantly different from the Agility Training group at p = 0.03.
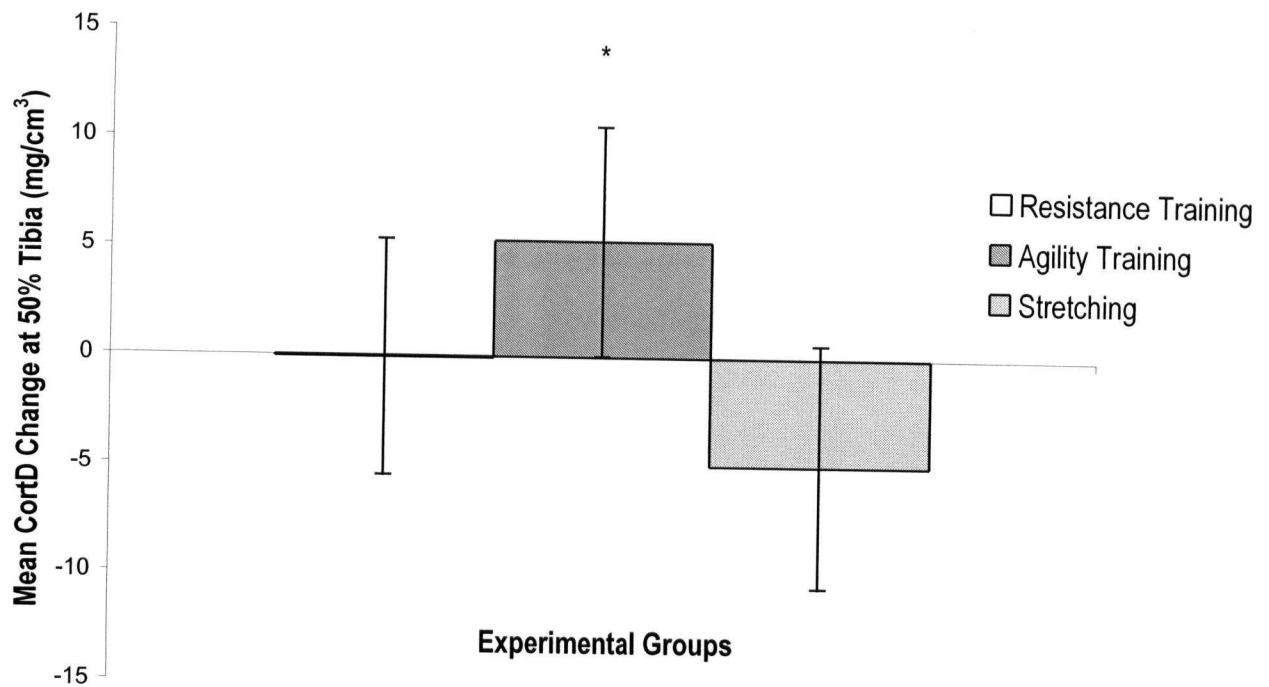
Figure 11. Mean change in cortical bone density (CortD in mg/cm$^3$) at the 50% site of the left tibia.
*Significantly different from the Stretching group at p = 0.02.
Error bars represent 95% confidence intervals.
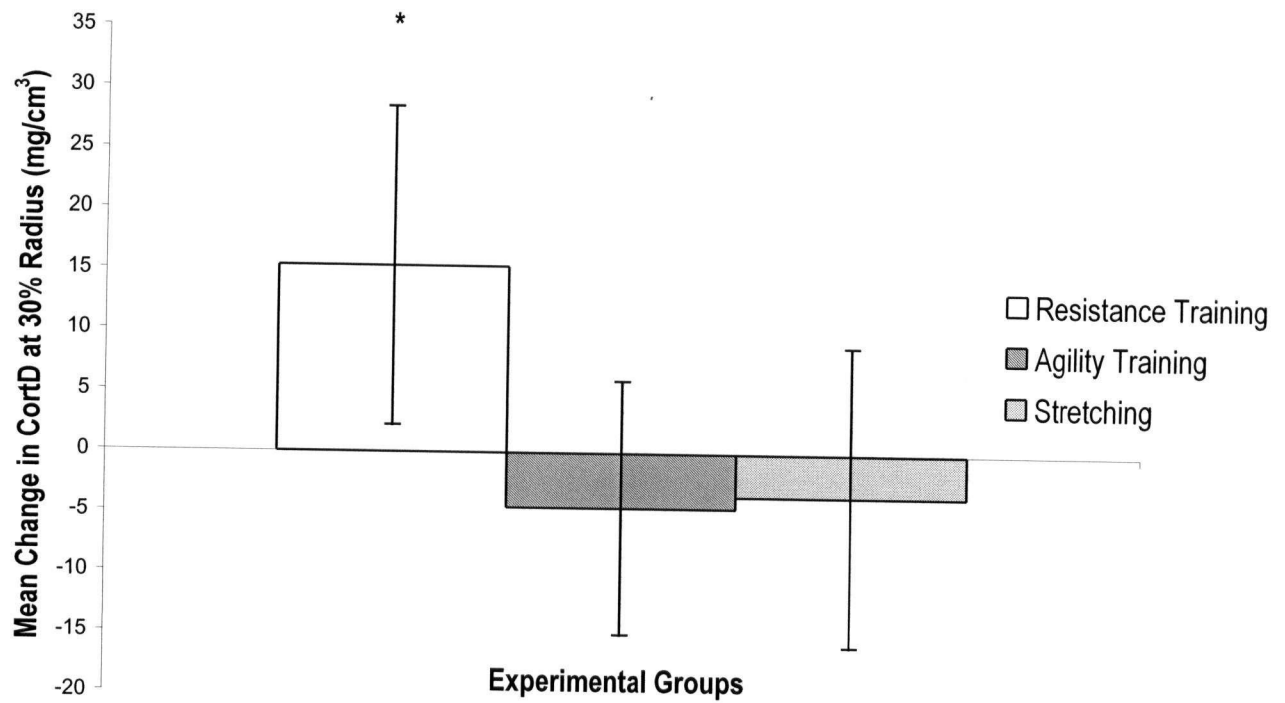
Figure 12. Mean change in cortical bone density (CortD in mg/cm$^3$) at the 30% site of the left radius. *Significantly different from the Agility Training group at p = 0.03. Error bars represent 95% confidence intervals.

## 7.4 Discussion

This chapter reports a significant increase in cortical bone density following an exercise intervention at both the shaft region of the left tibia and the radius in older postmenopausal women who had low bone mass at baseline. This finding is novel and challenges the general perception that cortical bone may not be as responsive as trabecular bone to mechanical stimulus in the aging skeleton. However, the finding of significant increases in cortical bone density did not result in concomitant increases in polar stress/strain index. This is likely secondary to the lack of significant structural changes found in this study. As stress-strain index (SSI) is density-weighted polar section modulus, both the structural and material properties of cortical bone directly influence this measure of bone strength.

To date, longitudinal human studies utilizing pQCT are few (13,194,363), and to my knowledge, with the exception on one recently published study, none have examined the shaft region of long bones (194). Uusi-Rasi et al. (194) found that a 12-month jumping program had no significant effect on cortical bone density, cortical area, or BSI at the 50% site of the tibia in early postmenopausal women (i.e., within 5 years after menopause). Thus, it is not possible to compare these findings with our results of significant increase in cortical density in 79 year-old women who had osteoporosis or osteopenia at baseline. Also, there is little or no evidence for the tissue or cell level mechanisms associated with bone adaptation following exercise in older postmenopausal women or in animal studies (160). However, indirect evidence from both animal and human studies support the findings of the present study.

In three year-old turkeys (i.e., aging skeleton), after 8 weeks of mechanical loading, there was greater osteonal mean wall thickness and a lengthened intracortical remodelling period compared with one year-old turkeys (158). Thus, mature bone may increase cortical bone mass by increasing osteonal mean wall thickness (160). Also, a 10-week program of treadmill running led to a significant increase in ultimate stress in the femur of 25 month-old female rats (159). Ultimate stress was calculated from the force to break the femur, the moment of inertia, and half the bone diameter measured parallel to the line of force application. The significant increase in ultimate stress was not associated with an increase in moment of

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inertia. These data suggest that the femur of 25 month-old female rats may have improved material properties, such as density, in response to mechanical loading.

Broadly speaking, cortical bone density may increase in at least four mechanisms: 1) decreased bone resorption (e.g., calcium supplementation), 2) increased bone formation (e.g., anabolic agents), 3) secondary mineralization of bone tissue (e.g., bisphosphonates), and 4) increases in selective osteoblast development of progenitor cells (e.g., parathyroid hormone). Evidence from both animal and human studies indicate that exercise decreases the rate of bone resorption in the postmenopausal skeleton (258-260,265,285). Two studies found no significant increase in circulating serum osteocalcin (a bone formation marker) despite significant increase in areal BMD by DXA (260,285). The authors suggested that exercise increased bone mass by inhibiting resorption rather than by stimulating bone formation. This suggestion is supported by the significant reduction in pyridinium crosslinks, a biomarker of bone resorption, after 6 months of exercise in older adults (men and women) aged between 50 and 73 years (284).

Evidence from animal studies also supports the hypothesis that the beneficial effects of exercise on bone are predominately mediated through the inhibition of bone resorption rather than by stimulation of bone formation. In the tibiae of 12 month-old OVX rats (ovariectomized at 10 months of age) that exercised (treadmill running) for four months, there was a decrease in osteoclast perimeter without a significant effect on osteoblast number or bone incorporation of $^{45}$calcium (258). Thus, the significant increase in cortical density at both the shaft region of the tibia and the radius in the present study may be due to decreased bone resorption. This would require bone biomarkers for verification. In Uusi-Rasi's (194) 12-month randomized controlled exercise trial, exercise did not have a significant effect on either bone formation or resorption biomarkers. Finally, the increased cortical density I observed may also be due to the bone remodelling transient (118).

The adaptation in cortical bone density at the tibial shaft in the Agility Training group may relate to mechanical loading of bone. Of the three experimental groups, the Agility Training program likely induced the most mechanical loading (i.e., alterations in strain rate and distribution) to the lower extremities as the

protocol included dynamic movements that were multi-directional, accelerating-decelerating, and of moderate impact (e.g., running and hopping; ground reaction force of 2 to 4 times body mass (274)). In contrast, both the Resistance Training program and the Stretching program consisted only of slow and controlled movements and the participants were primarily in a seated or standing (stationary) position. It is also plausible that the Resistance Training group demonstrated an increase in cortical bone volumetric density in the shaft region of the radius as this was the only experimental group that performed activities that loaded the forearm. The loading, however, was indirectly induced by muscle activity. Thus, increases in cortical bone density appear to be site-specific. Site-specificity of overall bone response (i.e., cortical and trabecular compartments combined) to exercise has been shown previously (12) but such a pattern within cortical bone has only been shown in animal studies (364).

### 7.5 Limitations

This study has several limitations. First, the midshafts of the tibia and radius are not clinically relevant sites of fractures in older adults with low bone mass. Although pQCT is limited in its ability to assess the proximal femur, the 4% site of the radius would have been useful to assess the effects of different types of exercise on this clinically fracture relevant and predominately trabecular site[7]. Furthermore, the relationship between a 0.5% or a 1.4% increase in cortical bone density in the shaft region of long bones as assessed by pQCT and fracture risk of the appendular skeleton (e.g., Colles' fracture) is unknown. Second, the relatively large variability (SD) in the pQCT outcome measures may have decreased the statistical power of this study to detect between-group differences. This large variability observed in the pQCT outcome measures is likely due to the single slice method used in this study. Single slicing assesses only small sections of bone (2.2 mm) so anatomical variations within those small areas can have large effects on the data (363). Third, the trial was not likely of sufficient duration, or possibly intensity, to observe all the potential benefits of mechanical loading on bone, such as the hypothesized increase in cross-sectional area. Finally, although I attempted to account for the use of

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[7] We sought to assess the 4% site of the radius but were not able to use these data secondary to the high failure rate in analysis (32%) despite attempts with different masks.

bisphosphonates by stratification and statistical analysis, this study design and number of participants does not truly separate the influence of exercise from the use of bisphosphonate therapy on bone health. However, I do contend that this cohort is representative of older postmenopausal women with confirmed low bone mass in terms of bisphosphonates use and thus, increases the generalizability of this study's results to this population.

## 7.6 Summary and Future Directions

In postmenopausal older women with low bone mass, 25 weeks of agility training and resistance training induced significant increases in cortical bone volumetric density at the shaft region of both the left tibia and radius, respectively. This novel finding suggests that mechanical loading has a positive influence on the material property of cortical bone in the aging and postmenopausal skeleton. In conclusion, these data highlight the **potential** for group-based resistance and agility training programs to reduce fracture risk in those with low bone mass. Further research is needed to determine the exact mechanism(s) responsible for this bone adaptation to mechanical loading and whether such density increases would be observed in clinically relevant sites (e.g., proximal femur and ultradistal radius).

This and the previous chapter reported bone changes and reduced fall risk after 25-weeks of exercise intervention. I am optimistic that such exercise intervention programs (agility and resistance training), if implemented on a wide scale, may provide a mechanism to reduce fracture, although this remains to be assessed. Behaviour is also an important variable in the fracture risk equation as both fall risk and bone health can be strongly influenced by individual choices. For example, an individual may significantly curtail or avoid physical activity (e.g., walking outside or walking down stairs) secondary to a fear of falling. This behaviour can increase both fall risk by impairing neuromuscular function (e.g., muscle weakness and slowed reaction time) and bone fragility by removing the necessary stimulus of mechanical loading. On the other hand, a women with healthy bones and little physiological fall risk may place herself at risk of fracture by making unsafe choices of activities (e.g., changing a light bulb by standing on an

unstable stool). Chapter Eight outlines complementary data regarding fear of falling in participants in the randomized controlled trial described in Chapters Six and Seven.

## Chapter Eight: Part Five

### 8.1 Introduction[8]

As discussed in previous chapters, falls are a relatively common event in older adults. While the fear of falling is a common psychological consequence of falling, this fear is also frequently reported by older adults who have not fallen. Prevalence rates of fear of falling vary, from about 30% in older adults who do not have a history of falling to 60% in those who have (18,365). The prevalence of fear of falling is higher among women than men (299,366,367). Fear of falling can lead to activity restriction that is self-imposed rather than strictly due to physical impairments (299). Thus, fear of falling is an independent contributor of functional decline and consequently, loss of independence among older adults (300).

Fear of falling has been associated with poor performance on tests of balance, including increased spontaneous sway and decreased one-leg stance time (366), reduced gait speed (368), reduced independence, poor quality of life, poor health (300), and depressed mood (367). Fear of falling has also been identified as an independent predictor of falls in community dwelling older adults in a 20-month, population based, prospective study (369).

A number of instruments have been developed to assess the fear of falling. These instruments range from a simple question of "Are you afraid of falling?" with a "yes/no" or "fear/no fear" response format to more sophisticated instruments that assess fear of falling by measuring fall-related self-efficacy, or one's self-confidence in the ability to avoid falling performing everyday activities. The Falls Efficacy Scale (FES) (370) and the Activities-Specific Balance Confidence Scale (ABC) (371) are two such widely-used instruments. Both scales were modeled using Bandura's theory of self-efficacy (372). Self-efficacy refers to an individual's perception of capabilities within a particular domain of activity. For instance, a person with a high degree of fall-related self-efficacy might tend to engage in more challenging activities, while a person with a low degree of fall-related self-efficacy would tend to avoid such activities. There are

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[8] A version of this chapter has been accepted for publication. Liu-Ambrose T, Khan KM, Eng JJ, Lord SR, McKay HA. Balance confidence increases with resistance or agility training: Increase is not correlated with objective changes in fall risk and physical abilities. Gerontology, 2004 (In Press).

important differences between the FES and the ABC. Because it primarily measures simple indoor activities, the FES is most applicable in older adults who are homebound and have low mobility (301,373). The ABC on the other hand examines a wider continuum of activity difficulty, including situations or activities of daily living performed outside the home, and thus, is more appropriate for use in higher functioning older adults.

Considering that there is a strong association between fall-related self-efficacy and physical function (365,368), and that poor fall-related self-efficacy leads to the loss of independence, deteriorating quality of life, and impaired function (300), interventions, such as fall prevention programs, could simultaneously improve physical function and balance confidence. Exercise can significantly improve fall-related self-efficacy, or balance confidence (92,107,301,302). I hypothesize that participating in a group-based exercise program has the potential to augment low balance confidence by improving quality of life, increasing social interaction with peers, reducing anxiety and physical frailty.

It is important that any enhancement of balance confidence is accompanied by an appropriate change or improvement in physical abilities. To my knowledge, there are no prospective reports that correlate change in balance confidence, as assessed by a fall-related self-efficacy scale, with change in physical abilities as induced by participating in a group-based exercise program. Furthermore, very little data exist on balance confidence in older people with low bone mass (301). As individuals with low bone mass are susceptible to sustaining fall-related fractures, their balance confidence may not be as amendable as previously reported in other populations (301,302).

Thus, the primary purpose of this 13-week prospective study was to examine the relationship between the change in balance confidence, as measured by the ABC Scale, and the changes in fall risk and physical abilities in older women with confirmed low bone mass after 13 weeks of exercise participation. As physical activity curtailment is a common consequence of fear of falling, the secondary purpose of this study was to examine the relationship between the change in balance confidence and the change in physical activity level.

## 8.2 Methods

### 8.2.1 Study Design

The study design has been described in Chapter Six, Section 6.2.1. However, the results of this study are based on the first 13 weeks of the trial.

### 8.2.2 Participants

The sample comprised women aged 75 to 85 years old who participated in the randomized, controlled prospective study of three different types of group-based exercise programs (resistance training, agility training, and general stretching) as described in Chapter Six, Section 6.2.2.

### 8.2.3 Measurements

8.2.3.1 Descriptive Variables

**Height and Mass**

Standing height was measured to the nearest millimetre using a wall-mounted stadiometer, and body mass was measured with an electronic scale to the nearest 0.1 kilograms. For both height and mass, I used the mean of two values or the median of three values for analysis.

**Questionnaires**

General health was assessed by a sub-set of questions from the Canadian Multicentre Osteoporosis Study (CaMOS) questionnaire (349) that relate to current medication use, the presence of associated medical conditions known to be fall risk factors (such as osteoarthritis), and fall history (in the last 4 weeks). This questionnaire was administered at baseline by trained interviewers. As well, all participants underwent a physician assessment (Dr. Lynda Thayer) to confirm current health status and health history. Cognitive state was assessed using the 30 point Mini-Mental State Examination (348). Use of a walking aid was also recorded.

8.2.3.2 Physical Performance

**Fall Risk**

Each participant's fall risk was assessed using the short form of Physiological Profile Assessment (PPA) © (16)as described in Chapter Six (Table 14). A PPA fall risk score was calculated for each individual. In my pilot study, the ICC of the PPA fall risk score for a cohort of 21 women aged 75 to 85 years was 0.78 (95% CI 0.46 to 0.91).

**Gait Speed**

Differences in gait performance have been observed between older nonfallers and fallers in cross-sectional studies (374,375). Also, reduced gait speed is associated with fear of falling (376). Furthermore, decreased gait speed has been identified as a significant and independent predictor of hip fracture risk in older women (287).

To control for the effects of different shoes (between trials and among individuals), participants were asked to walk without shoes and without the use of walking aids along an 8-meter path, first at a self-selected speed and then at a fast-paced but safe speed. Gait speed was calculated from the mean of three trials. The cumulative distance and time of consecutive strides (i.e., from foot contact with one leg to the next foot contact with the same leg) were recorded by infrared-emitting diodes (Northern Digital) attached to the foot during the middle section (i.e., approximately a 4-meter section, representative of constant gait speed) of the 8-m walkway.

**General Physical Function**

General physical function was assessed using the Community Balance and Mobility Scale (CB&M Scale) (351). This scale is a performance-based balance and mobility measure consisting of 12 items each rated at a 5-point scale (maximum of 85 points). It includes items such as timed single leg stand, tandem walking, and stair mobility. This novel scale was chosen because present balance and mobility measures do not adequately assess high-level function (315,352).

### 8.2.3.3 Balance Confidence

Balance confidence was assessed by the 16-item Activities-specific Balance Confidence Scale (371), with each item rated from 0% (no confidence) to 100% (complete confidence). The maximum score achievable is 1600, which is then averaged over the 16 items to provide a score out of 100. This scale is reported to have a two-week test-retest reliability of ICC = 0.92 and internal consistency Cronbach's alpha of 0.96 (371). The ABC score is correlated with other measures of self-efficacy, distinguishes between individuals of low and high mobility, and corresponds with balance performance measures (301,368).

### 8.2.3.4 Physical Activity Level

Each participant's current level of physical activity was determined by the PASE questionnaire that is valid and reliable for older adults (353,354). Its score is significantly associated with physiologic and performance characteristics (354).

### 8.2.3.5 Compliance

Adherence with the assigned exercise program was recorded for each participant and the compliance is expressed as the percentage of the 48 classes (maximum number of classes) attended.

### *8.2.4 Randomization*

After baseline measurement, participants were randomly assigned (by random draw) to one of three groups: Resistance Training, Agility Training, and Stretching (sham exercise). Randomization was stratified by baseline postural stability (total sway path; eyes open standing on foam), baseline total hip areal BMD and the use of bisphosphonates (yes/no).

### *8.2.5 Exercise Intervention*

The exercise intervention began one week after baseline measures were completed and participants were required to attend their assigned exercise class twice weekly as outlined in Chapter Six, Section 6.2.6.

### *8.2.6 Statistical Analysis*

Data were analyzed using SPSS (Windows Version 11.0) statistical software. Data were checked with scatterplots to eliminate errors and outliers (greater than 3 SD above or below the mean). Dependent

variables were checked for normality by calculating skewness and kurtosis. If the ratio of each statistic to its standard error is less than 2 or greater than –2, this indicates a normal population distribution (333). Descriptive data are reported for variables of interest (i.e., mean, standard deviation, and range). The overall alpha error was set at $p \leq 0.05$.

Comparisons of group characteristics and baseline scores were undertaken using a Chi Square test for differences in proportions and ANOVA for differences in means. A repeated measures analysis of variance model was constructed to determine the between- and within-group differences in balance confidence after 13 weeks of exercise participation. I determined the level of association between change in balance confidence and the following variables for the entire cohort ($N = 98$) using the Spearman rank correlation coefficients: change in fall risk score, change in postural stability, change in gait speed, change in general physical function, and change in physical activity level. Change was calculated as the post-intervention value minus the baseline value. I used the Spearman rank correlation coefficient as the distribution of the change scores for balance confidence was not normally distributed.

Effect size (ES; delta index) and percent change were also calculated for fall risk score, postural stability, gait speed, general physical function, balance confidence, and physical activity level. Effect size was calculated by subtracting the mean baseline value from the mean post-intervention value and dividing the result by the baseline standard deviation (318). Percent change was calculated by subtracting the mean baseline value from the mean post-intervention value, dividing by the mean baseline value, and multiplying by 100.

## 8.3 Results

### 8.3.1 Descriptive Variables, Baseline Values, and Exercise Adherence

The mean age of the cohort was 79 ± 3 years (Table 22). The participants had normal neurological and musculoskeletal function by physician examination. Table 23 provides the baseline values for the outcome measures. In the entire study cohort, adherence to the exercise classes was 83%. The

Resistance Training group had an average compliance of 85%, the Agility Training group 87%, and the Stretching group 79%.

### 8.3.2 Balance Confidence

Baseline balance confidence was not significantly different among the three groups (p = 0.86). There was a significant main effect of time (within-group effect) for balance confidence after 13 weeks of exercise intervention (p = 0.002). Subsequent analysis (paired t-tests) indicated that while both the Resistance Training group and the Agility Training group improved balance confidence after the 13-week intervention period (p ≤ 0.03), the Stretching group did not (p = 0.73) (Table 23). Both groups significantly improved balance confidence by 6% from baseline.

### 8.3.3. Spearman Rank Correlation Coefficients

Correlations between the (change) variables of interest are shown in Table 24. Change in balance confidence after 13 weeks of exercise intervention was not significantly correlated with change in fall risk score, postural stability, gait speed, or physical activity level. Although change in balance confidence was significantly associated with change in general physical function, it was a weak association (rho = 0.21). Figures 13 to 17 illustrate the relationship between these change variables.

### 8.3.4 Effect Size & Percent Change

The largest effect size was observed in fall risk score (-0.81) and the smallest effect size was observed in balance confidence (0.19). Table 25 lists the effects sizes and percent changes for the variables of interest.

Table 22. Descriptive statistics for descriptor variables (N = 98).

| Variable* | Resistance (n = 32) Mean (SD); Range | Agility (n = 34) Mean (SD); Range | Stretching (n = 32) Mean (SD); Range | Entire Cohort (N = 98) Mean (SD); Range |
|---|---|---|---|---|
| Age (yr) | 79.6 (2.1); 75 to 86 | 78.9 (2.8); 75 to 86 | 79.5 (3.2); 75 to 86 | 79.3 (2.7); 75 to 86 |
| Height (cm) | 160.1 (6.0); 148.0 to 172.0 | 157.0 (6.1); 144.0 to 167.2 | 158.3 (8.4); 139.6 to 178.9 | 158.5 (7.0); 139.7 to 178.9 |
| Body Mass (kg) | 59.9 (9.4); 47.2 to 83.2 | 62.5 (9.3); 47.2 to 89.2 | 65.2 (12.6); 36.6 to 96.2 | 62.5 (10.77); 36.6 to 96.2 |
| Medications | 2.6 (2.3); 0 to 9 | 3.2 (2.1); 0 to 7 | 4.1 (3.3); 0 to 17 | 3.3 (2.6); 0 to 17 |
| MMSE (max 30 pts) | 28.7 (1.4); 25 to 30 | 28.6 (1.4); 24 to 30 | 28.3 (1.9); 23 to 30 | 28.6 (1.6); 23 to 30 |
| Fall in Last 4 Weeks[†] | 5 (15.6) | 1 (2.9) | 2 (6.3) | 8 (8.2) |
| Osteoarthritis[†] | 11 (34.4) | 13 (38.2) | 17 (53.1) | 41 (41.8) |
| Knee Osteoarthritis[†] | 5 (15.6) | 6 (17.6) | 6 (18.8) | 17 (17.3) |

*There were no significant differences among the groups for any variable.
[†]Count (%). Count = Number of "yes" cases within each group. % = Percent of "yes" cases within each group.

Table 23. Descriptive statistics for outcome measures at baseline and after 13-weeks of exercise training (N = 98).

| Variable* | Resistance (n = 32) Mean (SD); Range | Agility (n = 34) Mean (SD); Range | Stretching (n = 32) Mean (SD); Range |
|---|---|---|---|
| *Baseline* | | | |
| Fall Risk Score (SD) | 2.22 (0.70); 1.15 to 4.08 | 2.40 (0.86); 0.48 to 4.24 | 1.92 (0.83); 0.29 to 3.32 |
| Postural Stability (mm) | 230.10 (93.09); 86.42 to 421.58 | 219.20 (80.26); 97.49 to 379.68 | 216.97 (104.72); 66.97 to 513.46 |
| Normal Gait Speed (m/s) | 1.02 (0.25); 0.52 to 1.60 | 1.02 (0.19); 0.66 to 1.43 | 0.91 (0.20); 0.34 to 1.21 |
| Fast Gait Speed (m/s) | 1.47 (0.35); 0.78 to 2.24 | 1.39 (0.26); 0.88 to 1.91 | 1.27 (0.27); 0.51 to 1.70 |
| General Physical Function[†] (max 85 points) | 44.6 (21.6); 0 to 78.0 | 39.9 (17.5); 8.0 to 73.0 | 40.4 (18.3); 10.0 to 81.0 |
| Physical Activity Level[‡] | 98.00 (51.78); 17.90 to 224.13 | 83.29 (35.07); 31.93 to 169.86 | 76.30 (30.01); 24.99 to 160.24 |
| Balance Confidence[§] (max 100 points) | 76.3 (22.7); 5 to 99.4 | 78.3 (14.5); 42.2 to 98.1 | 75.6 (23.7); 18.8 to 100.0 |
| *13-Weeks* | | | |
| Fall Risk Score (SD) | 1.39 (0.98); -0.93 to 3.97 | 1.49 (0.97); -0.16 to 3.17 | 1.50 (0.95); 0.02 to 3.66 |
| Postural Stability (mm) | 183.6 (123.2); 79.9 to 570.5 | 179.5 (98.1); 70.2 to 474.4 | 196.6 (122.9); 70.2 to 629.0 |
| Normal Gait Speed (m/s) | 1.11 (0.22); 0.58 to 1.53 | 1.09 (0.19); 0.71 to 1.57 | 1.00 (0.19); 0.47 to 1.34 |
| Fast Gait Speed (m/s) | 1.52 (0.33); 0.83 to 2.24 | 1.55 (0.27); 0.96 to 2.16 | 1.41 (0.28); 0.70 to 1.92 |
| General Physical Function[†] | 49.5 (20.7); 0 to 75.0 | 51.5 (15.5); 18.0 to 82.0 | 45.8 (17.8); 9.0 to 81.0 |
| Physical Activity Level[‡] | 108.7 (44.3); 11.9 to 427.3 | 116.6 (70.2); 42.9 to 203.9 | 115.1 (58.1); 25.0 to 317.2 |
| Balance Confidence[§] | 80.9 (17.1); 57.5 to 96.9** | 83.2 (12.2); 41.2 to 98.4** | 76.3 (17.6); 21.2 to 98.8 |

*High fall risk scores and high postural stability values indicate impaired performances. Higher gait speed values indicate better performance.
[†]Measured by the Community Balance and Mobility Scale where higher values indicate better physical function.
[‡]Measured by the PASE questionnaire where higher values indicate higher physical activity levels.
[§]Measured by the ABC Scale where higher values indicate lower levels of fear of falling.
**$p < 0.05$ compared with baseline value (paired t-test).

Table 24. Spearman rank correlation coefficient matrix between balance confidence and variables of interest. Balance confidence (ABC Scale score), postural sway (mm), normal gait speed (m/s), fast gait speed (m/s), general physical function (Community Balance and Mobility Scale), and physical activity level (PASE score).

| | Δ Fall Risk Score | Δ Stability | Δ Normal Gait | Δ Fast Gait | Δ Function | Δ Activity |
|---|---|---|---|---|---|---|
| **Δ Balance Confidence** | -0.01 | -0.02 | 0.06 | -0.03 | 0.21* | 0.05 |

*Significantly correlated at $p \leq 0.05$.

Table 25. Effect sizes (delta index) and percent changes observed for balance confidence, fall risk score, postural stability, gait speed, general physical function, and physical activity level (N = 98).

| Variable | Effect Size* | % Change* |
|---|---|---|
| Fall Risk Score (SD) | -0.81 | -33.12 |
| Postural Stability (mm) | -0.34 | -16.04 |
| Normal Gait Speed (m/s) | 0.38 | 8.25 |
| Fast Gait Speed (m/s) | 0.40 | 8.65 |
| General Physical Function† (max 85 points) | 0.40 | 17.92 |
| Physical Activity Level‡ | 0.58 | 33.60 |
| Balance Confidence§ (max 100 points) | 0.19 | 4.50 |

*Negative effect sizes and percent changes in fall risk score and postural stability indicate improvement. Positive effect sizes and percent changes in gait speed, general physical function, physical activity level, and balance confidence indicate improvement.
†Measured by the Community Balance and Mobility Scale (CB&M Scale) where higher values indicate better physical function.
‡Measured by the PASE questionnaire where higher values indicate higher physical activity levels.
§Measured by the ABC Scale where higher values indicate lower levels of fear of falling.
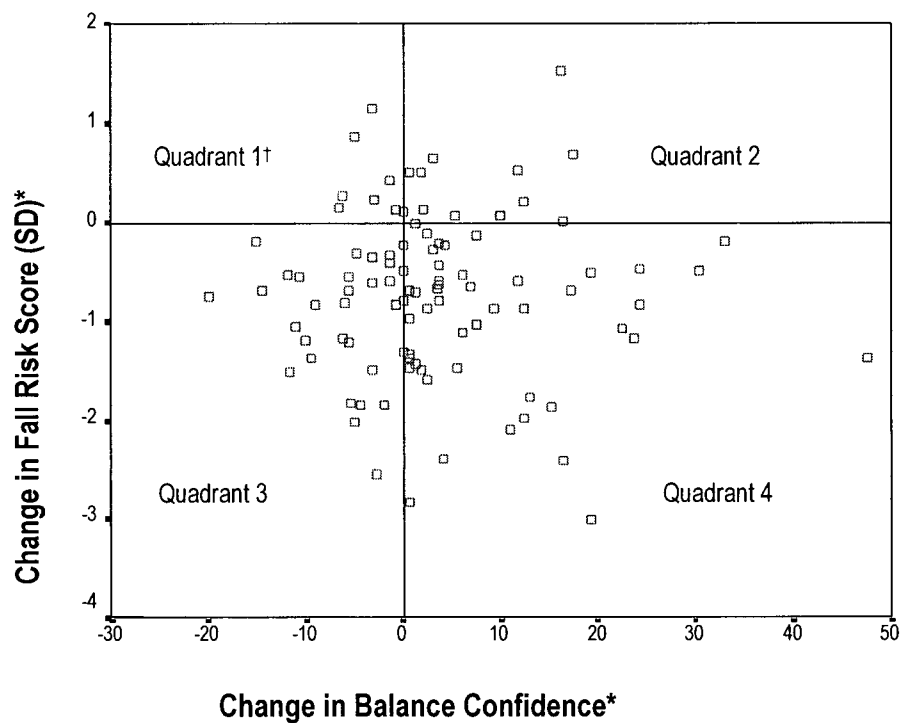
Figure 13. Scatterplot of change in fall risk score versus change in balance confidence.
*Negative change value in fall risk score (PPA composite score) indicates improvement. Positive value in balance confidence (ABC Scale) indicates improvement.
†Quadrants 2 and 3 indicate discordance between changes in fall risk score and balance confidence.
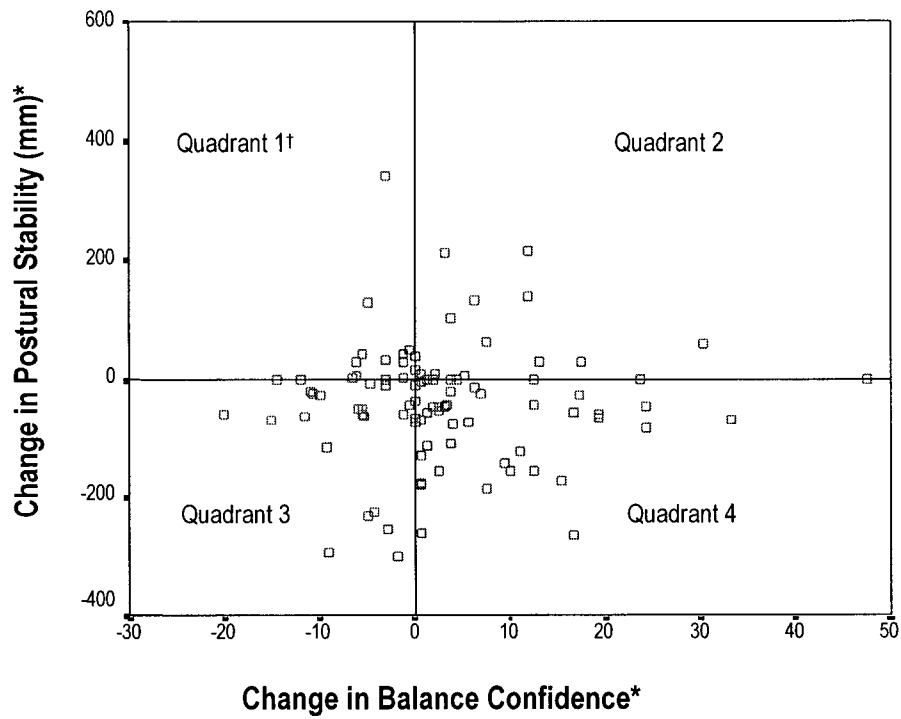
Figure 14. Scatterplot of change in postural stability versus change in balance confidence.
*Negative change value in postural stability (mm) indicates improvement. Positive value in balance confidence (ABC Scale) indicates improvement.
†Quadrants 2 and 3 indicate discordance between changes in postural stability and balance confidence.
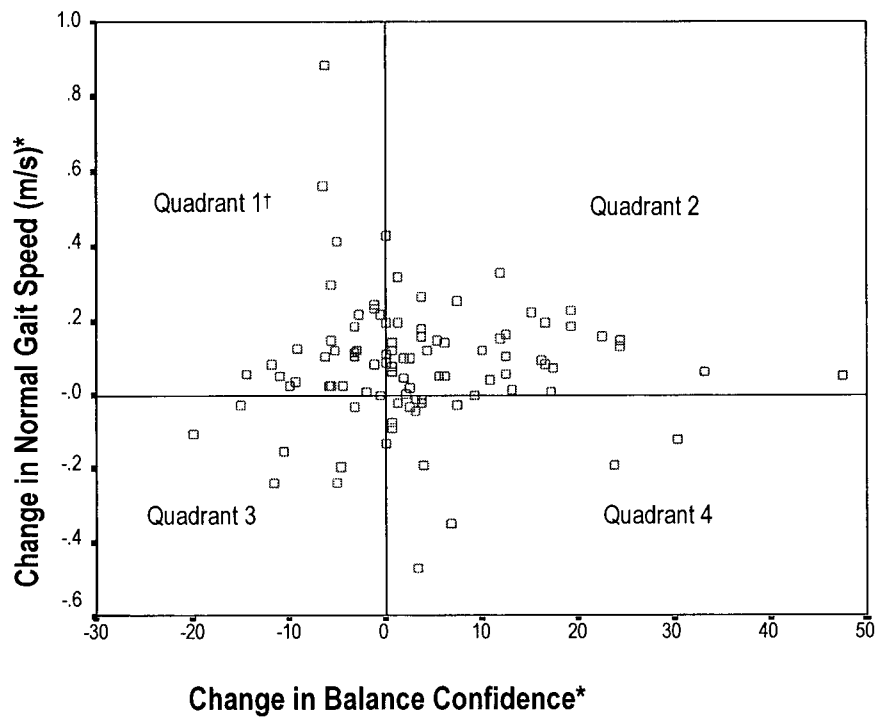
Figure 15. Scatterplot of change in normal gait speed versus change in balance confidence.
*Positive change in gait speed (m/s) and in balance confidence (ABC Scale) indicates improvement.
†Quadrants 1 and 4 indicate discordance between changes in gait speed and balance confidence.
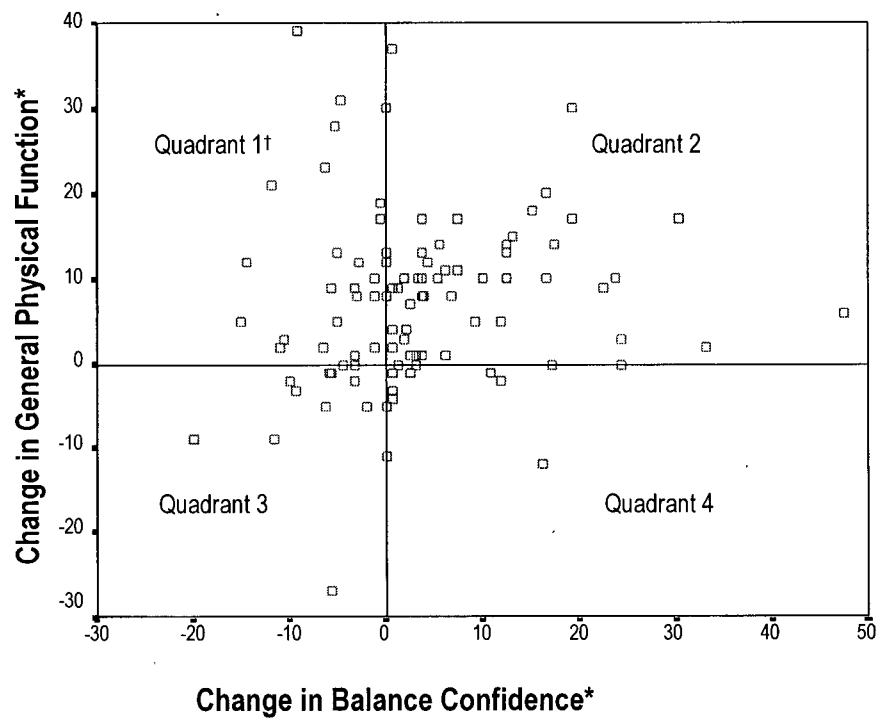
Figure 16. Scatterplot of change in general physical function versus change in balance confidence.
*Positive change in general function (CB&M Scale) and in balance confidence (ABC Scale) indicates improvement.
†Quadrants 1 and 4 indicate discordance between changes in gait speed and balance confidence.
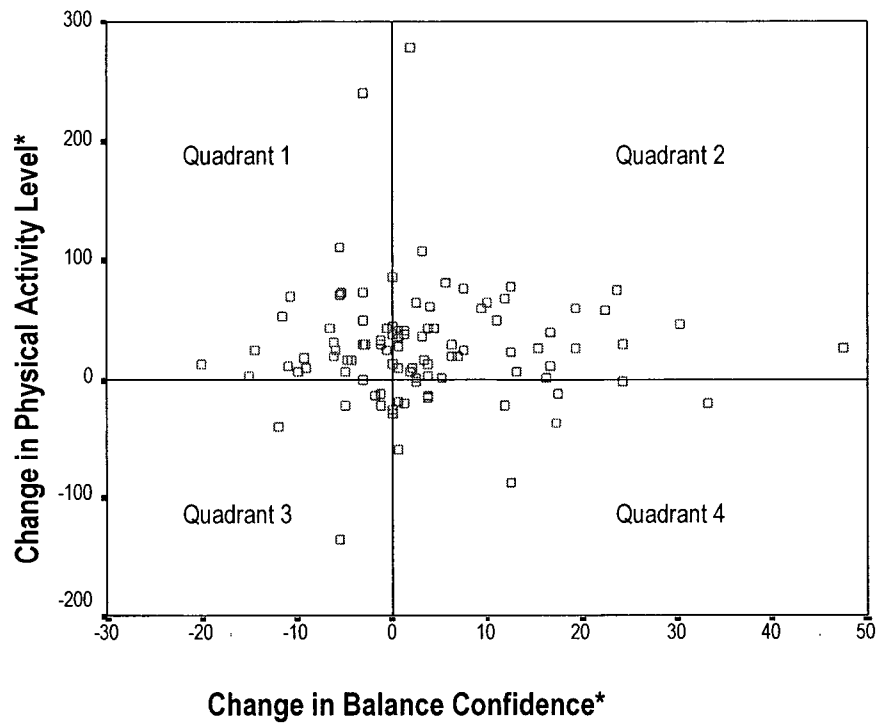
Figure 17. Scatterplot of change in physical activity level versus change in balance confidence.
*Positive changes in physical activity level (PASE score) and in balance confidence (ABC Scale) indicate improvement.
†Quadrants 1 and 4 indicate discordance between changes in physical activity level and balance confidence.

## 8.4 Discussion

I found that both high-intensity resistance training and agility training, but not general stretching, significantly enhanced balance confidence in older women with confirmed low bone mass. The mean ABC scores for the Resistance Training group and the Agility Training group were 80 and 83, respectively, after 13 weeks of training. According to Myers et al. (301), ABC scores 80 and above are indicative of highly functioning, physically active older adults. To my knowledge, this is the first study that has examined the effect of different types of exercise programs on balance confidence in older adults. It is noteworthy that resistance training alone improved balance confidence. This has not been demonstrated before as previous exercise interventions that enhanced balance confidence all encompassed balance training (92,107,301,302). Furthermore, the enhancement of balance confidence with exercise in a population of individuals at high risk of sustaining fall-related fractures and of falls is an important finding.

Importantly, this study found that change in balance confidence, as assessed by the ABC scale, did not significantly correlate with change in fall risk, postural stability, gait speed, or physical activity level after 13 weeks of participating in either resistance training, agility training, or general stretching. Change in balance confidence was, however, significantly associated with change in general physical function. While previous prospective exercise intervention studies (92,301,302) have reported improvement in physical abilities with a concomitant reduction in the fear of falling, these studies did not report change score correlations.

The effect sizes (and percent changes) calculated indicate that the influence of exercise on balance confidence was of a much lower magnitude than that of exercise on fall risk, postural stability, gait speed, general physical function, and physical activity level. These findings may be due to the disparity between the variables of interest in their potential for change or improvement. For instance, the mean baseline ABC score for the cohort was 77. This is comparable to the scores (low 80s) obtained in a previous study involving individuals with osteoporosis (301). According to Myers et al. (301), individuals who score in the mid-80s or better on the ABC are unlikely to show further improvement in balance

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confidence while there is room for improvement for those scoring below 80. Thus, the potential for improvement in balance confidence in this cohort may have been limited. In contrast, the mean baseline fall risk score for the cohort was 2.18 (Table 23), which represents a net performance of 2.18 standard deviations inferior to the age-matched mean. This indicates a marked risk of falling and thereby, implies a greater potential for improvement.

The scatterplots (Figures 13-17) indicate that some women's changes in balance confidence were discordant with changes in fall risk, postural stability, gait speed, general physical function, or physical activity level. This underscores that balance confidence is not a measure of postural stability -- and it was never designed to be one. The observation of balance confidence enhancement in the presence of increased fall risk or deterioration in physical ability raises concern as it implies that such an individual may partake in activities that are beyond her physical abilities, and consequently, increase her risk of falling. Thus, although fear of falling is a pervasive and serious problem in older adults (367), my data suggest that caution needs to be exercised when implementing strategies to enhance balance confidence so that confidence does not become elevated far beyond physical abilities.

There are several possible reasons for the observed patterns of change in balance confidence and fall risk and physical abilities. One may relate to the nature of the study cohort. The cohort consisted of older women with confirmed low bone mass, who are at a greater risk of sustaining fall-related fractures compared with age-matched healthy counterparts. Assuming that individuals in this cohort are cognisant of this elevated risk of fracture, their balance confidence may be more resistant to change than their physical abilities and participation in physical activity. I acknowledge that some degree of fear of falling may be prudent in those at risk of sustaining fall-related fractures. The issue of what is the "appropriate" amount of fear of falling, or an optimal confidence to mobility ratio, as well as what might constitute a "gold-standard" for this psychological variable warrants further research.

Second, the exercise intervention programs did not include any education specifically targeting fear of falling. As fear of falling is a psychological entity and multifactorial in etiology, a multidimensional

approach to decrease fear of falling, such as combining exercise intervention with fall education, may prove more efficacious than exercise alone in enhancing balance confidence.

Third, the lack of specificity between the training programs and the 16 items of the ABC Scale may have decreased the efficacy of the intervention. The exercise programs did not specifically "train" the participants in the activities of the ABC Scale (e.g., riding an escalator holding onto the rail), but perceived self-efficacy will only generalize to highly similar situations (372).

Fourth, balance confidence may have been elevated beyond an improvement in physical capacity in some participants secondary to increased socialization and support with study participation. Balance confidence may also have been positively affected by the sense of personal achievement associated with successfully attending the weekly exercise classes (e.g., managing to use public transit and driving alone to the centre).

The results of this study highlight that partaking in exercise alone may increase balance confidence in the absence of improved physical abilities in older women with low bone mass. A clinical corollary of this study is that those who design group-based exercise programs for community-dwelling older adults (e.g., fitness instructors and physical therapists) should consider including an education component on factors that influence fear of falling.

## 8.5 Limitations

The lack of consistency observed between change in balance confidence and the changes in fall risk and physical abilities may be due to psychosocial factors that underpin fear of falling. Both the fear of social embarrassment and concerns about damage to social identity are feared consequences of falling (377,378). As these fears were not assessed in this study, I am unable to determine the contribution of these factors to my findings but recommend that these behavioural determinants be given further research attention.

## 8.6 Summary and Future Directions

Both resistance training and agility training significantly improved balance confidence in community-dwelling older women with low bone mass after 13 weeks of participation. However, contrary to the proposed hypothesis, the change in balance confidence did not significantly or strongly correlate with changes in fall risk, postural stability, gait speed, and physical activity level. This may be due to differences in the potential for change in the variables of interest, the nature of the cohort examined, the need for a multidimensional approach to decrease fear of falling, training specificity, and increased social interaction with peers. Of particular concern, is the observation of at least some discordance between balance confidence change and changes in fall risk and physical abilities. Thus, those who design group-based exercise programs for community-dwelling older adults should consider including an education component on factors that influence fear of falling. Future studies are needed to develop interventions that would achieve greater concordance between the fear of falling and physical abilities in older adults.

## Chapter Nine:  Conclusions and Future Directions

### 9.1 Overview

This thesis explored several questions ultimately related to fracture risk in older people with osteoporosis and osteopenia.  In the cross-sectional studies of this thesis, I (i) examined the association between back pain and two fall risk factors (postural stability and functional mobility), and (ii) compared the level of three fall risk factors (postural stability, functional mobility, and quadriceps strength) in older women with, and without, osteoporosis.  Then, in a randomized controlled trial, I examined the effects of different types of exercise on two domains of fracture risk, fall risk and bone health, in older women with low bone mass.  In that intervention I also examined how a recently-recognized psychological variable -- fear of falling, changed as a result of the interventions I undertook.  Here I draw research conclusions and provide a summary of the clinical implications and potential for knowledge translation that can result from this thesis.

### 9.2 Back Pain May Warrant Scrutiny As A Fall Risk Factor In Older Women With Osteoporosis

In Chapter Four, I reported that back pain was negatively associated with both postural stability and functional mobility in older women with osteoporosis (379).  Given that back pain may respond to various treatments (81,380-382), one could speculate that the data suggest back pain deserves attention when screening older women for fall risk.  On the other hand, these are the first data to examine this question and the cross-sectional nature of this small study limits the conclusions that can be drawn from it.

The study provides important pilot data for future studies examining causal relationships between back pain and fall risk.  Thus, future population studies should ascertain the degree of back pain that exists in older people who fall and those who suffer fall-related fractures, as well as measuring other well-established fall and fracture risk factors, such as impaired muscle strength (9).  To date, back pain has not often been examined as a risk factor for falls or non-vertebral fracture.

These findings led me to include a measure of back pain in the randomized controlled trial that I performed (see below).  It may be possible that exercise interventions that aim to reduce fall risk factors

such as muscle weakness and postural instability may also reduce back pain at the same time. This should be examined in future studies. Future studies of interventions specifically for back pain (e.g., manual therapy) might consider including measures of postural stability and functional mobility as secondary outcomes in the light of the data reported in Chapter 4.

## 9.3 Fall Risk Reduction (Not Just Amelioration Of Bone Mass) Should Be A Priority For Older Women With Osteoporosis

In Chapter Five, I reported that older women with osteoporosis had greater level of fall risk (factors) than their counterparts without osteoporosis (346). The clinical implications of these results are that fall risk screening and, where appropriate, intervention may be of particular importance in older women with osteoporosis. However, only future prospective population studies can confirm whether older women with osteoporosis suffer more falls compared with their age-matched healthy counterparts. Such studies should account for the known confounders (e.g., muscle mass and osteoarthritis) as much as possible and adjust for those in the analysis as appropriate.

This cross-sectional study provides impetus for future larger studies that seek to determine the underlying mechanisms for the differences in fall risk factors observed in this study between older women with osteoporosis and those without it. These studies must match the participants on a number of factors (e.g., age, physical activity, comorbid conditions, and mobility). Possible mechanisms for differences in postural stability to be explored are: centre of pressure and centre of gravity parameters during quiet standing, muscle recruitment patterns elicited during perturbations and their timing (i.e., latency) and response magnitude, and the relationship between these measures (of postural stability and neuromuscular function) and different degrees of kyphosis. Muscle biopsies would allow the comparison of local factors (e.g., number of muscle fibers) that contribute to strength between those with osteoporosis and those without osteoporosis. Prospective measures of physical activity (e.g., pedometer readings for 4 weeks) may also provide insight as to reasons for differences in muscle strength.

## 9.4 Both Resistance Training And Agility Training Reduce Fall Risk In Older Women With Low Bone Mass

The randomized controlled trial described in Chapters Six and Seven is the first to compare *two* different types of exercise on *both* fall risk and bone health in older women with low bone mass. I found that both high-intensity resistance training and agility training significantly reduced fall risk compared with a general stretching program in older women with low bone mass (383). The resistance training program reduced fall risk by 57% and the agility training program reduced fall risk by 48%. These substantial fall risk reductions support the implementation of resistance training and agility training in fall risk reduction programs.

As I used surrogate outcome measures for both falls and fractures, future randomized controlled trials powered to measure falls, and ideally injurious falls or fractures, are needed to determine if both types of exercise programs are effective in reducing actual falls, injurious falls or fractures. My data suggest that a 12-month intervention study powered for falls as an outcome in this population would require about 300 (150 per group) participants in total with a cost of between $300,000 to $500,000. Such a study should involve health economists so that it has the potential to include cost-effectiveness analysis if it proves successful in reducing falls. The magnitude of a study powered for fracture as an outcome is discussed below.

I was part of a Canadian Institute of Health Research-funded Workshop on research directions for falls in 2003 and it appears that future research in this area include focus on (i) better understanding of mechanisms underpinning postural stability including balance recovery strategies, (ii) innovative interventions aimed at reducing falls, and (iii) possibly identifying protective devices or compliant flooring to reduce the impact of falls, particularly in high-risk environments. My data are relevant to parts (i) and (ii) as the finding that resistance training led to improved postural stability is novel. I would like to pursue further studies in a biomechanics laboratory to examine the role of muscle strength, the rate of development of muscle torque, and reaction time of key muscles (e.g., tibialis anterior) in maintaining postural stability.

Also, the type of agility training program I used in the study has not been used previously and I envision undertaking more sophisticated laboratory studies in a smaller population to examine the mechanism whereby this training influenced postural stability.

My clinical experience as a physiotherapist, together with my research understanding of falls epidemiology makes me aware that falls are not only important in those with osteoporosis but that other high-risk groups also exist. One such group includes those people with stroke, another, those with cognitive impairment. There is recent evidence that exercise may promote neural plasticity (384). Cognitive impairment is present in 10% of individuals older than 65 and 60% of those older than 85 years. Individuals with cognitive impairment have 2.2 times greater risk of injurious falls (24) and 1.7 times the mortality of normal older adults (385). To date, research has not ascertained which domains of cognition are most important for falls prevention. Thus, there is a need to identify the specific dimensions of cognition most strongly associated with falls in older adults and my planned postdoctoral training will allow me to address these questions. Also, although epidemiological data suggest that physical activity may minimize cognitive decline associated with normal aging, it is not well known if exercise can significantly improve those aspects of cognitive function associated with falls. This is an important area of fall research.

**9.5 Both Resistance Training And Agility Training Increase Bone Density In A Site-Specific Manner In Older Women With Low Bone Mass**

In Chapter Seven, I reported that both high-intensity resistance training and agility training significantly increased cortical bone density in the appendicular skeleton. Also, both types of exercise programs augmented bone health in a site-specific manner. Resistance training increased cortical bone density by 1.4% in the shaft of the radius and agility training increased cortical bone density by 0.5% in the shaft of the tibia. This randomized controlled trial provides prospective DXA and novel pQCT data on the oldest cohort studied to date (mean age of 79 years). Such increases in cortical bone density observed with both resistance training and agility training have not been shown in other populations.

As no other published prospective exercise studies have examined cortical bone density in the older human postmenopausal skeleton, there is no "benchmark" against which to compare the bone results of this study. Although OVX animal studies provide valuable information regarding the effects of exercise on bone, the animal skeletons do not mirror the human skeleton. For example, the rat, a commonly used animal model in bone research, continues to grow throughout life. The only published prospective study to date that examined the effect of exercise on cortical bone density (in the tibial shaft) found no significant change after 12 months of intervention (194). However, this study's cohort consisted of early postmenopausal women (i.e., within 5 years after menopause) who have very different hormone status and bone structure than do the women examined in this thesis.

As cortical bone density has a direct effect on whole bone strength, the results of this study support the implementation of resistance training and agility training in fracture prevention programs. However, future prospective multi-centre population studies are needed to determine if cortical bone density in the shaft regions of the appendicular skeleton are associated with fracture risk. Such observational studies generally require in the order of 1,000 to 15,000 people depending on the length of observation (9,287,342,343) and whether the primary outcome includes all fractures or hip fractures alone. Given that pQCT is not yet widely available, it will likely be at least a decade before such data are available, if at all.

To test whether exercise would reduce fracture rates by increasing cortical bone density would be even more difficult than an observational study seeking associations between cortical bone density and fracture because of the sample size required for adequate statistical power with intervention studies. Gregg et al. (386) estimated that a 5-year study examining the effects of exercise on hip fractures in 75 year old women, that assumed an alpha = 0.05, a control group fracture incidence rate of 3 to 6% over the 5 years, and a risk reduction of 25% with the exercise intervention, would need from 3467 to over 7000 people **per** group. The use of an aggregate endpoint (e.g., any fracture) could increase power by increasing event rates, but the exercise intervention may be less effective on non-hip outcomes.

Also, studies are needed to delineate the mechanisms associated with bone adaptation following exercise in postmenopausal women. The technique of cortical bone biopsy allows examination of changes in osteonal wall thickness, porosity, and Haversian canal diameters. While it would be ideal to perform these biopsies of cortical bone at the sites that are clinically relevant and most affected by the exercise intervention (e.g., proximal femur), cortical bone biopsies are commonly taken, in vivo, from the ilium. Bone biomarkers of both formation and resorption would also provide valuable insight as to the mechanisms underpinning changes in bone turnover rate with exercise in this population. For example, anti-resorptive agents that are the current mainstay of treatment act, as their name suggests, by reducing bone resorption. Whether exercise acts in this way or by augmenting *bone formation* has not been well investigated in older populations.

**9.6 Exercise Reduces Fear Of Falling, But This May Increase Fall Risk**

In Chapter Eight, I reported that both high-intensity resistance training and agility training reduced fear of falling after 13 weeks of participation. However, change in balance confidence did not significantly or strongly correlate with change in fall risk, postural stability, gait speed, general physical function, or current physical activity level. Thus, although fear of falling is a pervasive and serious problem in older adults (367), the results suggest that caution needs to be exercised when implementing strategies to enhance balance confidence so that confidence is not elevated beyond actual physical abilities.

Future studies are needed to determine interventions that would achieve concordance between the fear of falling and physical abilities in older adults. However, prior to such studies, more work is needed to identify the determinants of fear of falling. Much of the research to date of fear of falling has been on its prevalence (367) and its relationship with falls, physiological function, frailty, and quality of life in older adults (300,365,366,368,369). Little has been done to examine the factors that contribute to the fear of falling. For example, both the fear of social embarrassment and concerns about damage to social identity are newly-established consequences of falling (377,378). To date, these and other behavioural determinants of fear of falling are not well explored and should be given further research attention.

## 9.7 The Role of Exercise in Health

This thesis focused on exercise training in an at-risk group (i.e., secondary prevention of fractures). The intervention described would also be suitable as primary prevention strategies for community-dwelling adults. Booth et al. (387) argued that, "exercise intervention and exercise biology are vital and potentially effective components of our arsenal in the war on chronic disease." Exercise is certainly attractive as a mean of primary prevention of chronic disease as it can be relatively inexpensive (e.g., walking, running, and cycling) and is widely accessible. For fracture prevention in older adults, exercise is the only therapeutic modality that targets multiple risk factors simultaneously (62). Physical inactivity increases the incidence of physical frailty while exercise maintains bone mass (387).

Although it is well accepted that weight-bearing exercise has a role in the prevention and management of osteoporosis, the types of exercise that are often prescribed is walking and stretching. Resistance training, especially of high-intensity, and agility training are not commonly prescribed and clinical experience suggests that many clinicians question their safety for individuals with low bone mass. Furthermore, I contend that the common perception is that older adults, with or without low bone mass, do not have the physical capabilities of participating in such exercise programs. My randomized controlled trial (383) demonstrated that not only are high-intensity resistance training and agility training safe for older adults but that older women are physically capable of participating in such programs. Of course, both programs, especially the agility training program, required careful planning and a high ratio of instructors to participants to ensure safety. Nevertheless, agility training programs may become more feasible in the general community setting in the future if safe environments can be created. For example, a gym floor with greater compliance to absorb impact would drastically reduce the risk of fall-related fractures during agility training. The development of an effective hip protector that is comfortable to wear, fits well, and even visually appealing would also contribute to making agility training more safe. However, more research is needed to develop such surfaces and equipment.

Despite the many undisputed benefits of exercise, is it not often used or thought of as a mean of primary prevention (387). I contend this is especially true in the population of older adults. However, as the world's aging population continues to increase, exercise must begin to play a greater role in health promotion and primary prevention to effectively minimize health care costs and human suffering. In addition to providing novel data as to how resistance training may act via postural stability to reduce fall risk, the results of this thesis' randomized controlled trial provide strong evidence for each of resistance training and agility training, as an important component of health promotion in older women with low bone mass.

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# Chapter Ten:  Appendices

**Appendix One: Additional Data for Chapter Seven**

Table 26. Pearson product moment correlations of age, body mass, height, body composition, current physical activity level (PASE score), daily calcium dose (mg), daily vitamin D (IU), with cortical bone density, cortical bone content, cortical bone cross-sectional area, and stress-strain index (SSI) at 30% site of the left radius at baseline (N = 80).

| | Age | Body Mass | Height | Fat Mass | Lean Mass | PASE | Calcium | Vitamin D |
|---|---|---|---|---|---|---|---|---|
| **Cortical Bone Density** | -0.30* | 0.14 | 0.10 | 0.08 | 0.13 | 0.05 | 0.08 | 0.26 |
| **Cortical Bone Content** | -0.24* | 0.32** | 0.35** | 0.21 | 0.34** | -0.02 | -0.09 | 0.29 |
| **Cortical Bone Area** | -0.22* | 0.35** | 0.38** | 0.23* | 0.37** | -0.03 | -0.12 | 0.28 |
| **SSI** | -0.16 | 0.36** | 0.40** | 0.22 | 0.42** | -0.09 | -0.03 | 0.10 |

*$p < 0.05$
**$p < 0.01$

Table 27. Pearson product moment correlations of age, body mass, height, body composition, current physical activity level (PASE), and their changes, with 25-week change in cortical bone density, cortical bone content, cortical bone cross-sectional bone area, and stress-strain index (SSI) at 30% site of the left radius (N = 75).

| Change In: | Cortical Density | Cortical Content | Cortical Area | SSI |
|---|---|---|---|---|
| Age | 0.17 | 0.08 | 0.07 | 0.11 |
| Baseline Body Mass | -0.06 | -0.14 | -0.13 | -0.03 |
| Body Mass Change | -0.01 | 0.08 | 0.08 | 0.08 |
| Baseline Height | 0.05 | -0.13 | -0.16 | -0.00 |
| Height Change | -0.05 | -0.06 | -0.07 | -0.09 |
| Baseline Fat Mass | -0.05 | -0.16 | -0.17 | -0.05 |
| Fat Mass Change | -0.09 | 0.12 | 0.18 | 0.16 |
| Baseline Lean Mass | -0.05 | -0.08 | -0.07 | 0.01 |
| Lean Mass Change | -0.05 | -0.024 | -0.03 | -0.07 |
| Baseline PASE | -0.08 | 0.17 | 0.23* | 0.18 |
| PASE Change | 0.06 | 0.17 | 0.03 | 0.14 |

*$p < 0.05$
**$p < 0.01$

Table 28. Pearson product moment correlations of age, body mass, height, body composition, current physical activity level (PASE score), daily calcium dose (mg), daily vitamin D (IU), with cortical bone density, cortical bone content, cortical bone cross-sectional area, and stress-strain index (SSI) at 50% site of the left tibia at baseline (N = 97).

| | Age | Body Mass | Height | Fat Mass | Lean Mass | PASE | Calcium | Vitamin D |
|---|---|---|---|---|---|---|---|---|
| **Cortical Bone Density** | -0.11 | 0.16 | 0.10 | 0.06 | 0.22* | 0.01 | -0.19 | -0.42 |
| **Cortical Bone Content** | -0.22* | 0.36** | 0.37** | 0.22* | 0.40** | 0.00 | 0.37* | -0.32 |
| **Cortical Bone Area** | -0.23* | 0.37** | 0.39** | 0.24* | 0.40** | 0.00 | -0.37* | -026 |
| **SSI** | -0.17 | 0.39** | 0.43** | 0.23* | 0.48** | -0.01 | -0.34 | -0.22 |

*$p < 0.05$
**$p < 0.01$

Table 29. Pearson product moment correlations of age, body mass, height, body composition, current physical activity level (PASE), and their changes, with 25-week change in cortical bone density, cortical bone content, cortical bone cross-sectional bone area, and stress-strain index (SSI) at 50% site of the left tibia (N = 95).

| Change In: | Cortical Density | Cortical Content | Cortical Area | SSI |
|---|---|---|---|---|
| Age | -0.11 | -0.02 | 0.04 | 0.04 |
| Baseline Body Mass | 0.04 | 0.07 | 0.06 | -0.01 |
| Body Mass Change | 0.03 | -0.08 | -0.09 | -0.04 |
| Baseline Height | 0.06 | 0.07 | 0.04 | 0.00 |
| Height Change | 0.07 | -0.06 | -0.09 | -0.09 |
| Baseline Fat Mass | 0.04 | 0.09 | 0.08 | 0.02 |
| Fat Mass Change | -0.13 | -0.13 | -0.06 | -0.06 |
| Baseline Lean Mass | 0.06 | -0.01 | -0.04 | -0.06 |
| Lean Mass Change | 0.13 | -0.14 | -0.18 | -0.17 |
| Baseline PASE | -0.18 | 0.01 | 0.09 | -0.05 |
| PASE Change | 0.03 | 0.17 | 0.14 | 0.06 |

Table 30. Pearson product moment correlations of age, body mass, height, body composition, current physical activity level (PASE score), daily calcium dose (mg), daily vitamin D (IU), with total bone density, total bone content, and total bone area at 10% site of the left tibia at baseline (N = 97).

| | Age | Body Mass | Height | Fat Mass | Lean Mass | PASE | Calcium | Vitamin D |
|---|---|---|---|---|---|---|---|---|
| **Total Bone Density** | -0.14 | 0.22* | 0.21* | 0.18 | 0.17 | 0.09 | -0.22 | -0.14 |
| **Total Bone Content** | -0.19 | 0.48** | 0.46** | 0.34** | 0.48** | 0.12 | -0.40* | 0.15 |
| **Total Bone Area** | -0.02 | 0.20 | 0.19 | 0.12 | 0.28** | -0.03 | -0.29 | -0.03 |

*p < 0.05
**p < 0.01

Table 31. Pearson product moment correlations of age, body mass, height, body composition, current physical activity level (PASE), and their changes, with 25-week change in total bone density, total bone content, and total bone bone area at 10% site of the left tibia (N = 92).

| Change In: | Total Density | Total Content | Total Area |
|---|---|---|---|
| Age | -0.02 | -0.05 | 0.00 |
| Baseline Body Mass | -0.02 | 0.04 | 0.04 |
| Body Mass Change | 0.00 | -0.10 | -0.05 |
| Baseline Height | -0.08 | -0.04 | 0.07 |
| Height Change | -0.08 | -0.10 | 0.05 |
| Baseline Fat Mass | -0.01 | 0.04 | 0.02 |
| Fat Mass Change | 0.06 | -0.02 | -0.08 |
| Baseline Lean Mass | -0.10 | -0.05 | 0.10 |
| Lean Mass Change | 0.01 | -0.12 | -0.12 |
| Baseline PASE | 0.18 | 0.14 | 0.17 |
| PASE Change | -0.19 | -0.16 | 0.18 |

Table 32. Pearson product moment correlations of age, body mass, height, body composition, current physical activity level (PASE score), daily calcium dose (mg), daily vitamin D (IU), with total bone density, total bone content, and total bone area at 10% site of the left radius at baseline (N = 91).

| | Age | Body Mass | Height | Fat Mass | Lean Mass | PASE | Calcium | Vitamin D |
|---|---|---|---|---|---|---|---|---|
| **Total Bone Density** | -0.10 | 0.10 | 0.23* | 0.14 | -0.01 | -0.10 | -0.14 | -0.43 |
| **Total Bone Content** | -0.03 | 0.25* | 0.00 | 0.13 | 0.29* | 0.06 | -0.20 | -0.30 |
| **Total Bone Area** | -0.01 | 0.18 | 0.25* | 0.04 | 0.30** | 0.07 | -0.05 | 0.15 |

*p < 0.05
**p < 0.01

Table 33. Pearson product moment correlations of age, body mass, height, body composition, current physical activity level (PASE), and their changes, with 25-week change in total bone density, total bone content, and total bone area at 10% site of the left radius (N = 87).

| Change In: | Total Density | Total Content | Total Area |
|---|---|---|---|
| Age | 0.01 | -0.08 | -0.02 |
| Baseline Body Mass | -0.12 | -0.10 | -0.12 |
| Body Mass Change | -0.03 | -03 | 0.05 |
| Baseline Height | 0.12 | -0.05 | -0.10 |
| Height Change | 0.02 | 0.04 | 0.02 |
| Baseline Fat Mass | 0.12 | -0.11 | -0.11 |
| Fat Mass Change | -0.01 | -0.06 | 0.03 |
| Baseline Lean Mass | 0.13 | -0.05 | -0.12 |
| Lean Mass Change | -0.12 | 0.04 | 0.09 |
| Baseline PASE | -0.12 | 0.10 | 0.19 |
| PASE Change | 0.31** | -0.10 | -0.27* |

*p < 0.05
**p < 0.01

Table 34. Pearson product moment correlations of age, body mass, height, body composition, current physical activity level (PASE score), daily calcium dose (mg), daily vitamin D (IU), with areal BMD of total hip, trochanteric region, and femoral neck at baseline (N = 91).

|  | Age | Body Mass | Height | Fat Mass | Lean Mass | PASE | Calcium | Vitamin D |
|---|---|---|---|---|---|---|---|---|
| **Total Hip Areal BMD** | -0.16 | 0.55** | 0.38** | 0.46** | 0.49** | 0.15 | -0.60 | -0.08 |
| **Trochanter Areal BMD** | -0.17 | 0.48** | 0.45** | 0.35** | 0.47** | 0.22* | -0.43 | 0.09 |
| **Femoral Neck Areal BMD** | -0.11 | 0.48** | 0.35** | 0.39** | 0.44** | 0.13 | -0.54 | -0.18 |

*p < 0.05
**p < 0.01

Table 35. Pearson product moment correlations of age, body mass, height, body composition, current physical activity level (PASE), and their changes, with 25-week change in areal BMD of total hip, trochanteric region, and femoral neck at baseline (N = 89).

| Change In: | Total Hip Areal BMD | Trochanter Areal BMD | Femoral Neck Areal BMD |
|---|---|---|---|
| Age | -0.02 | -0.17 | 0.12 |
| Baseline Body Mass | 0.17 | 0.09 | 0.24* |
| Body Mass Change | 0.10 | 0.07 | 0.05 |
| Baseline Height | 0.02 | -0.04 | 0.23* |
| Height Change | -0.15 | -0.20 | -0.07 |
| Baseline Fat Mass | 0.16 | 0.06 | 0.14 |
| Fat Mass Change | 0.04 | 0.07 | -0.08 |
| Baseline Lean Mass | 0.18 | 0.13 | 0.33* |
| Lean Mass Change | -0.07 | 0.04 | -0.05 |
| Baseline PASE | -0.03 | -0.10 | -0.13 |
| PASE Change | 0.08 | 0.00 | 0.01 |
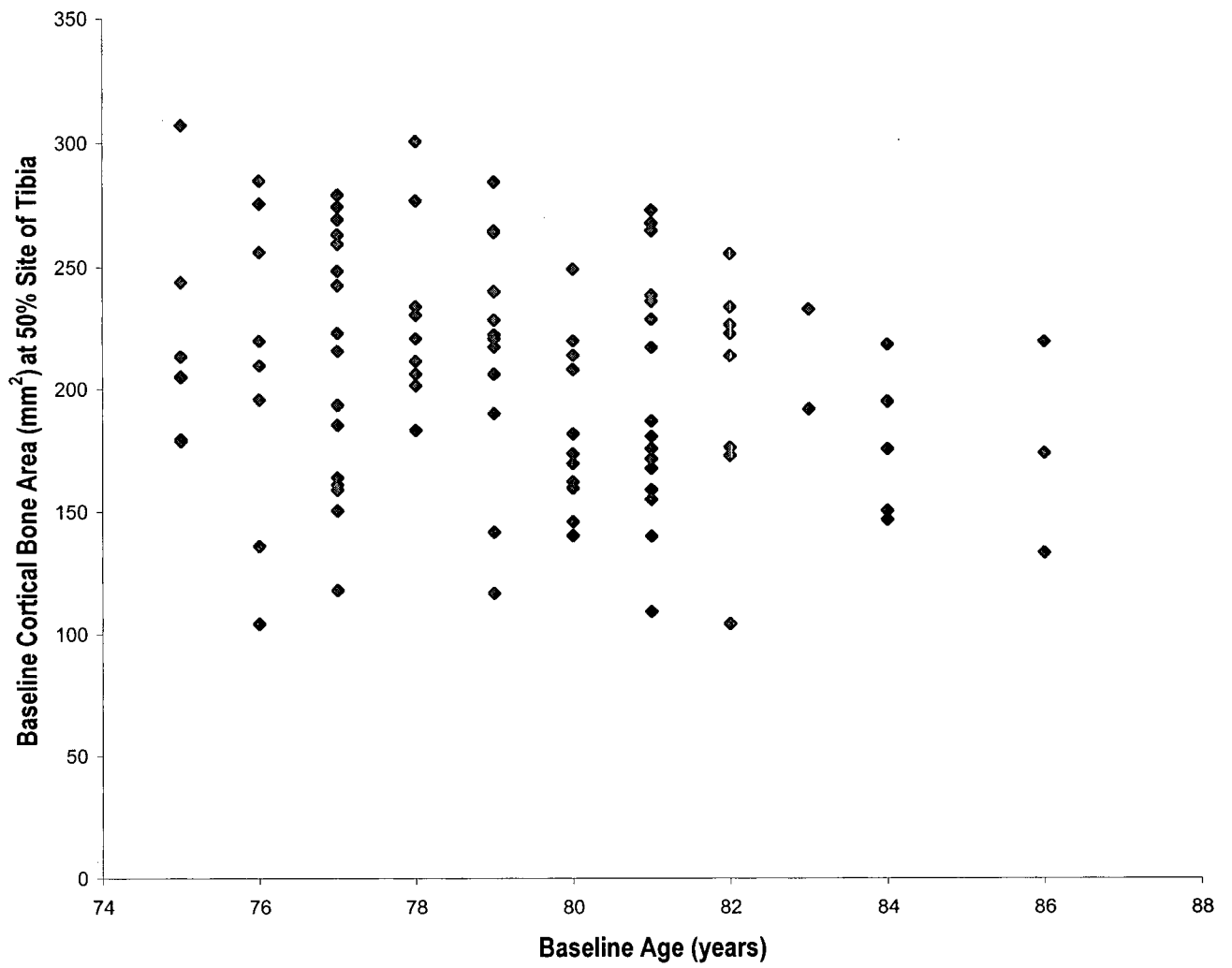
Figure 18. Scatterplot of baseline cortical bone area at 50% site of the tibia versus baseline age (N = 97).
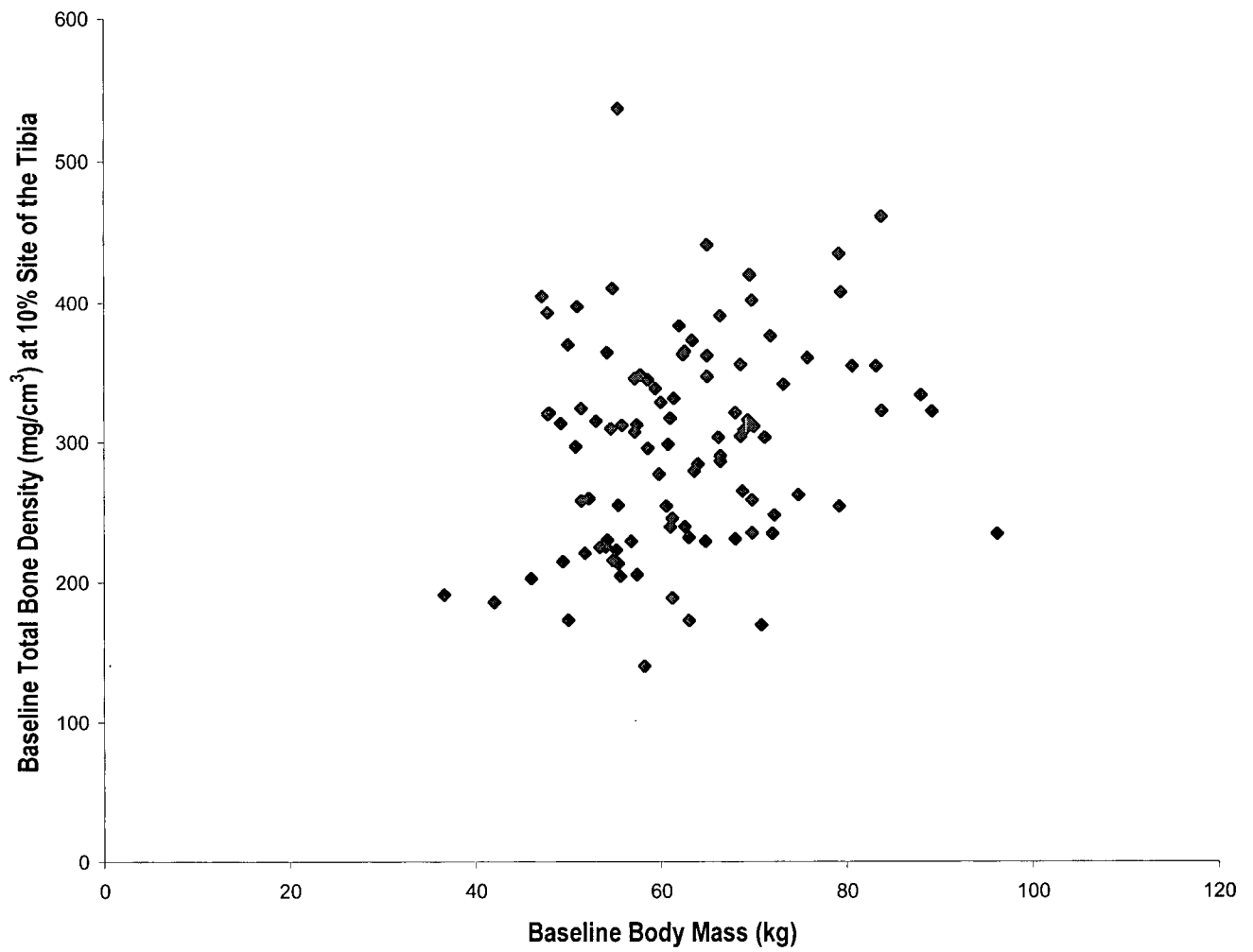
Figure 19. Scatterplot of baseline total bone density at 10% of the tibia versus baseline body mass (N = 97).
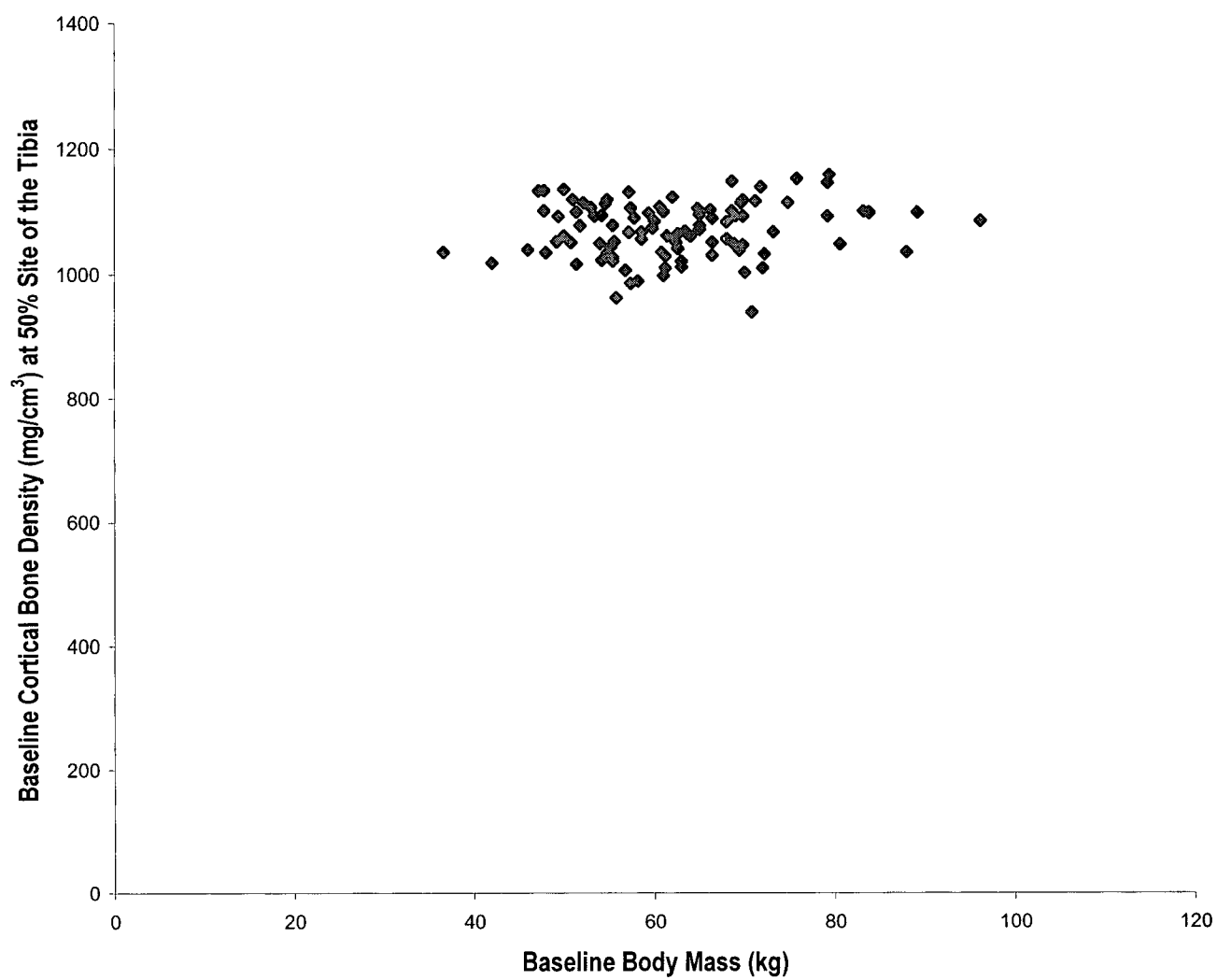
Figure 20. Scatterplot of baseline cortical bone density at 50% site of the tibia versus baseline body mass (N = 97).
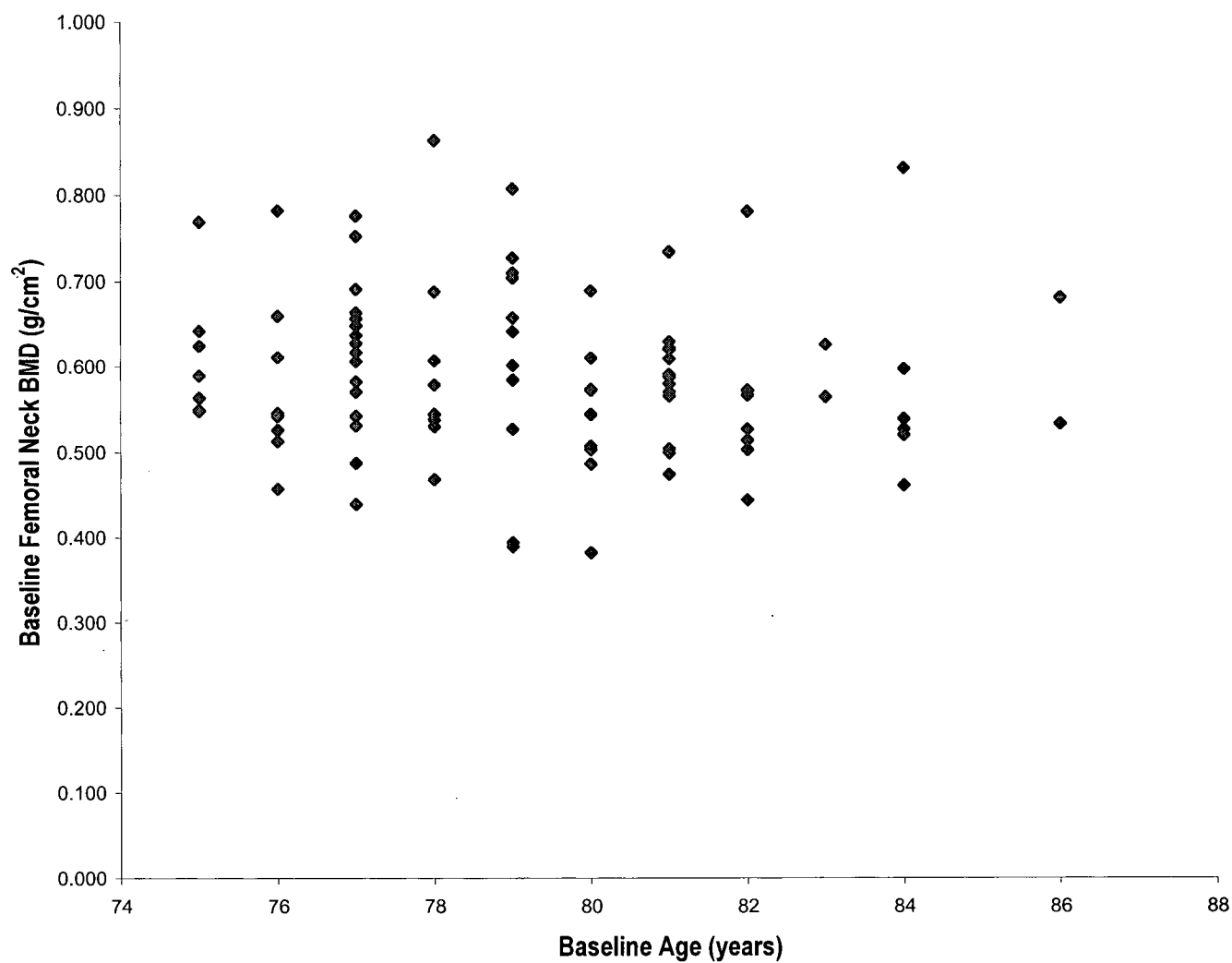
Figure 21. Scatterplot of baseline femoral neck areal BMD versus age (N = 93).

**Appendix Two: Information Letters and Consent Forms**

# Balance and Bone Health Study
# Information Letter and Consent Form

# Heather McKay PhD, Karim Khan MD PhD, Janice Eng PhD

Dear Participant,

Recent studies have shown that in women with osteoporosis, exercise can improve muscle strength, balance, enjoyment of life and reduce back pain. There are, however, few studies examining the effect of different types of exercise programs in women with osteoporosis. Therefore, we are inviting women with osteoporosis to participate in a study of physical activity, muscular strength and balance. The primary purpose of this study is to evaluate three different exercise programs over 10 weeks and 6-months. The exercise programs will be community-based designed specifically for women with osteoporosis.

Should you choose to participate in the study, you will be randomly assigned to one of three groups: 1) strength training, 2) balance training 3) posture and relaxation. Exercise classes will be offered daily and we will ask that you attend two classes per week. The results of our study will provide important information regarding the role of physical activity for increasing muscular strength and balance, and ultimately, preventing falls.

If you agree to participate, you will be asked to attend three measurement sessions. The first at the start of the study, the second at 10 weeks into the study and the final

measurement session will be at 6 months – the end of the study. Each measurement session is comprised of two parts, each taking about 90 minutes. The first part will take place at GF Strong Rehabilitation Centre (near BC Women's Hospital), and the second part will be conducted at the UBC Bone Health Research laboratory. Measurements taken at each of these sessions is clearly described on page 4 of this letter.

If after reading the study description carefully, you would like to learn more about the study, please call Teresa Ambrose at            Teresa will be pleased to answer any questions and provide you with details about an information session you may attend. At that time, you will be provided with details of the study and invited to ask questions.

Should you have any immediate questions about this study please contact Teresa Ambrose          Dr. Karim Khan (              ) or Dr. Heather McKay                ) at the University of British Columbia. Thank you for your interest in the study. We look forward to hearing from you.

Sincerely,

Dr. Karim Khan
Dr. Heather McKay
Dr. Janice Eng
Teresa Ambrose
Connie Waterman
The Bone Health Research Group

# Consent form

## BALANCE AND BONE HEALTH STUDY

Heather McKay PhD, Karim Khan MD PhD, Janice Eng PhD, Teresa Ambrose, Connie Waterman

**For further information or questions please contact:**
Teresa Ambrose, UBC Bone Health Research Laboratory
Phone Number:

**BACKGROUND:** Hip fractures, a painful consequence of osteoporosis, often occur as a result of a fall. Exercise programs may be an effective way of preventing both falls and fracture by improving balance, muscle and bone strength. However, there is a need to identify an optimal program to improve both balance and bone mass in women with osteoporosis.

**PURPOSE:** Our primary objectives are to investigate the effect of a 6-month strength training or agility training intervention program on quality of life, muscular strength, balance, and bone mass in 75-84 year old women with osteoporosis.

**STUDY PROCEDURE:** Your participation in this study will involve a 6-month exercise intervention program and 3 measurement sessions (start, 10 weeks, and 6 months). Each session is comprised of two 90-minute parts at the Bone Health Research Laboratory at the University of British Columbia and GF Strong Rehabilitation Centre in Vancouver.

**EXERCISE INTERVENTION:** Should you choose to participate in the study, you will be randomly assigned to one of three groups: 1) strength training, 2) balance training, or 3) posture and relaxation. Exercise classes will be offered daily and we will ask you to attend two classes per week. Classes will last for 60 minutes and continue for 6-months. A certified and trained instructor will supervise all classes.

**MEASUREMENT SESSIONS:** Prior to beginning the study in February, after 10 weeks, and at the end of the study in July, you will be asked to attend two measurement sessions. Each of these requires 90 minutes to complete. The first session will be conducted at GF Strong Rehabilitation Centre (Rehab Research Lab, GF Strong Rehab Centre, 4255 Laurel Street, Vancouver, BC) to assess balance and muscular strength. The second session will be conducted at the Bone Health Research Laboratory at the University of British Columbia (Room 209, Robert F. Osborne Centre, 6801 Thunderbird Boulevard, Vancouver, BC) to assess bone health.

The following measurements will be taken:

**Height and weight:** Each will be measured twice using standard procedures.

**Balance:** Your balance will be measured using a computerized balance system. As a part of this procedure you will be asked to maintain your balance under various conditions (movement of the perimeter or platform, eyes closed, eyes open). In addition, you will be requested to perform simple tasks such as standing on one leg, walking (forward and backwards), ascending and descending stairs. All tests are painless, commonly used to assess balance in older age groups and will be supervised by qualified persons.

**Muscular Strength:** The strength of your anterior thigh muscles will be assessed in the seated position. You will be asked to pull maximally against a strain gauge. This procedure is painless, safe, and is commonly used to assess strength in older age groups.

**Bone:** Whole body, hip and spine bone status will be evaluated using a bone densitometer. This procedure is painless and routinely used in modern medical practice. It requires only that you lie still on the padded measurement table for about 20 minutes. We will also assess changes in bone structure at the tibia using a peripheral computerized tomography system. This procedure is performed while you are sitting with your leg extended and takes approximately 10 minutes. Although the bone measurements are X-ray based, the total patient effective dose per session will be approximately 10 millirem. This is less than you receive on an airplane flight across the country. A trained operator will perform all the bone density measurements.

**Questionnaires:** Prior to having your bones assessed, you will be asked to complete questionnaires regarding your health history, nutrient intake, physical activity and quality of life. You will also be asked to record your food intake for 3 days after the first testing session. Questionnaires will take ~30 minutes to complete. A trained staff person will discuss these questionnaires with you.

**BENEFITS:** Strength training, balance, posture and relaxation exercises can improve muscle strength, balance, enjoyment of life, and reduce back pain. In addition to the exercise classes, information about ways to prevent falls, pain and fractures will be discussed with you. Previous participants in similar exercise programs in Vancouver have enjoyed meeting and interacting with other women in the study. You will also receive the results of your individual bone density, strength, and balance measurements at the end of the study along with a summary of the study findings.

**RISKS:** None of the measurements are known to cause a health risk. Mild muscle soreness and minor soft-tissue injuries are common when beginning any exercise program or increasing activity too quickly. To minimize the chance of injury, all exercises will be designed for your individual ability level and will progress slowly as your body adapts. Instructors who are specifically trained to work with your age group will conduct training. Qualified health professionals will be present at all measurement sessions.

**RIGHTS AND WELFARE OF THE INDIVIDUAL**: You have the right to refuse participation in this study. It is understood that you are free to withdraw from any or all parts of the study at any time without underlined affecting your right to medical care.

**CONFIDENTIALITY:** Your identity will remain confidential as all individual records and results will be analyzed and referred to by number code only and kept in the University of British Columbia Bone and Mineral Measurement Lab. The lab remains locked and only those directly involved in the study (namely, Drs McKay, Khan and Eng) will have access to your records and results. You will not be referred to by name in any study reports or research papers. Your individual results will remain confidential as they will not be discussed with anyone outside the research team.

Please be assured that you may ask questions at any time. We will be glad to discuss your results with you when they become available and we welcome your comments and suggestions. Should you have any concerns about this study or wish further information please contact Dr. Heather McKay            Dr. Karim Khan            at the University of British Columbia. If you have any concerns about your rights or treatment as a research subject, please contact a representative at the Office of Research Services and Administration at UBC

**PARTICIPANT CONSENT:** I understand that participation in this study is entirely voluntary and that I may refuse to participate at any time without any consequences to continuing medical care. I have a received a copy of this consent form for my own records. I consent to participate in this study.


_____          _____
Patient's Signature                                         Date


_____          _____
Witness Signature                                          Date


_____          _____
Investigator's Signature                                   Date

**Appendix Three:  Excerpts from Intervention Manual**

# Agility Class Week 13

1. Step-Lift & Hold Balance Transfer while walking around room. (1 minute)
   Try to hold the foot off the floor for 10 seconds before stepping forward.
   Progress to holding the foot off the floor for 6 seconds with eyes shut.
   Open them to step.

2. Tandem Walk-and-Hold around room. (1 minute)
   Stay in the tandem position for 10 seconds before taking the next step.
   Progress to holding eyes shut for last 6 seconds before taking next step.
   Open eyes to step.

3. Tandem Step-Lift around room. (1 minute)
   From a tandem position step and lift the knee, holding 2 seconds, then step into a tandem position and hold 2 seconds.

4. Modified Front & Back Layouts or "Tree" (45 seconds)
   Stand on one foot and extend other foot to front, side and back, leaning the body back, other side and front. Keep repeating for allotted time. Those who have not mastered the "Tree" should do so before attempting the "Layouts".

5. Grapevine/Side Step (1 minute)
   This activity poses a higher risk for falling so all instructors not leading are shadowing the less agile participants. Start slow and controlled and speed up with more rapid direction changes to challenge reaction times.

6. Agility Circuit 2 (4 minutes)

7. Robins Nest (4 minutes)

8. Partner Soccer Pass (2 minutes)
   Regroup participants into two teams with even numbers on each side of the room. Two people cross to the other side, passing inflated beach balls back and forth using their feet.

9. Partner Ball Pass (2 minutes)
   As above, passing the ball with their hands.

# Agility Class Week 16 (Total time 22 minutes)

* Staff: Clear chairs and put them away, except for those who need them for the cool-down. Those chairs are pushed against the wall.

1. Follow the Leader (2 minute)
   Line the participants up in a couple of rows against the mirror. The "leader" takes a variety of steps as she moves across the room. For instance,
   "Two steps to the side."
   "1 step forward"
   etc.

2. "Fly Swatters' Ball" (2 minutes)
   In partners, swat balloons back and forth to each other while crossing the room and back.

3. Agility Circuit 2 (8 minutes)

4. Captains Ball (4 minutes)
   Play 4 times. Each time, mix the team members up.

5. Partner Soccer Pass (2 minutes)
   Regroup participants into teams of two and have them move clock-wise in a circle around the room while passing the ball back and forth with their feet. After one minute, change positions so the other person is on the inside.

6. Partner Ball Pass (2 minutes)
   As above, passing the ball with their hands, with one bounce.

# Captain's Ball

Equipment:   1 ball for each team (4)
             Masking take to mark where team is to be lined up behind

Objective:   Be the first team to have everyone be the Captain
             Improve Reaction Time

Rules:

Create teams of 4 with 3 people lined up behind the line and the Captain standing facing the team 3 meters away.

The Captains tosses to ball to the first person and they return it then step to the side. The Captain tosses the ball to the second person. They return it then step aside. The Captain tosses it to the third person. They return it.

The first person comes forward to take be the Captain and the former Captain goes to the end of the line. The whole team moves forward so they are lined up behind the line.

This continues until everyone has had a turn at being the Captain. The first team to finish wins.

X   X   X                    X

X   X   X                    X

X   X   X                    X

X   X   X                    X

# Posture Class Core Component, Week 16

1.    **Hip Circles on ball**

2.    **Posture Check:**
> Seated, on ball or chair, hold "seated mountain pose" 20
> seconds. Repeat 8 times.

3.    **Kegel elevator:**
> Seated on ball or chair. Tighten pelvic floor, and pull up. Hold 8
> - 15 seconds. Repeat 8 times.
> Hold and slowly raise arms to front one at a time, then together
> (shoulder flexion).
> Hold and slowly slide out one foot at a time.
> Hold, combining arms and legs.

4.    **Rapid Kegel Contractions:**
> 1, 2, 3 count contracting on one, relaxing for two, three. Repeat
> 10 times.

5.    **Medial Rotator Stretch:**
> Seated, with arms flexed or straight, with upper arms close
> into sides.
> Externally rotate arms and hold 2 seconds.
> Repeat 8 times.

6.    **Chin Retraction:**
> Seated on chair or ball.
> Sit as tall as possible, then draw chin down chin as if beginning
> to nod "yes".
> Hold 5 seconds. Repeat 8 times.

7.    **Choice of:**   a) **Shoulder Blade Retraction**
> Seated or standing, retract shoulder blades without elevating
> them.
> Hold 3 –5 seconds. Repeat 10 times.

*OR*    b) **Wall Angel**
Standing against the wall, stand tall with shoulder blades against the

wall. Start with elbows low and flexed at 90°, shoulders externally

rotated so back of hands and forearm are touching wall (floor). Slowly

slide the hands up the wall (floor) without loosing contact of the wall

and keeping the elbows at 90° flexion. Stop sliding if this happens.

Hold 10 seconds. Repeat 5 times.

8. **TA Flatteners:**
   On mat, while maintaining a neutral spine.
   Flatten abdomen and hold for 10 seconds. Repeat 6 times.
   Flatten abs, hold, slowly pull up on toes and hold 5 seconds.
   Repeat 4 times
   Flatten abs, hold, slowly pull up on toes, then imagine the heels
   are resting on raw eggs. Hold 5 seconds. Repeat 4 times
   -Repeat above, then slowly push one raw egg out with heel still
   on floor, then draw it back, taking 5 seconds each way. Repeat
   on other side.

9. **Lat Stretch**
   On floor.
   Anterior shoulder flexion of both arms until beside ears, then
   press back into mat or wall while reaching up with arms.
   Hold 10 seconds.

10. **Ankle ROM**
    Circles, inversion, eversion.

11. **Cooldown, Deep Breathing, and Relaxation**

# Weight Training Core Component, Week 18

Purpose: To increase the strength of the upper and lower extremities

Format: Order of exercises is *upper/lower*. Please remind participants to stick to that as the
weights get heavier.

Sets are done in a circuit format, not back to back.
7 Rep Max (80% 1RM)
Training intensity, medium to heavy (80 – 100% effort)
Lifting and lowering (concentric and eccentric) time is equal.

| Exercise | Comments |
|---|---|
| Squats | Reps, maximum 10.<br>Most now have the technique sufficiently mastered to be able to carry weights.<br>Weights can be held down by the side, resting on the thigh, or with static elbow flexion.<br>Some may wish to replace this with the seated leg press. If so, have them do the lunges in the Triangle Room, then take their weights into the Circuit Room to do the biceps curls between sets of leg presses. |
| DB biceps curls | Hands supinated from start to finish. |
| Mini-lunges | Weights can be added only if their technique is correct. Most aren't ready yet. |
| Seated row | Use front pad to support body now that resistance is high. A towel can be used for comfort.<br>Take care to ensure that lumbar spine stays neutral. Form is paramount. |
| Seated leg curls | Mrs. X does standing leg curls. Ensure she does it with her knees in line but not touching. |
| Seated triceps press | Instructor lowers bar for participants to grasp onto to if they have difficulty reaching it. |

| | |
|---|---|
| Toe presses | Remind participants not to rush. Focus on full R.O.M. rather than trying to push the weight too much higher. |
| Bridging | Hold 5 - 10 seconds,<br>Repeat 10 times for 5 seconds or 5 times for 10 seconds.<br>Band is tied around knees, not higher up on thigh.<br>Knees should be hip width apart throughout. Watch they don't "relax" knees as they raise and lower the hips.<br>Those that are ready can begin to do a second "Bridge" set with one leg and no band. |

**Appendix Four: Questionnaires**

# FINAL ASSESSMENT (AUGUST 2002) – PHYSICAL ACTIVITIES

1. SINCE MARCH 2002, HAVE YOU STARTED ON A NEW PHYSICAL ACTIVITIES PROGRAM OR ROUTINE (OTHER THAN THE BONE AND BALANCE CLASSES)?

2. IF YES, PLEASE DESCRIBE THE PROGRAM OR ROUTINE (INCLUDE TYPE OF EXERCISE, FREQUENCY, AND DURATION).

3. SINCE MARCH 2002, HAVE YOU STOPPED PARTICIPATING IN A PHYSICAL ACTIVITIES PROGRAM OR ROUTINE (THAT YOU WERE INVOLVED IN PREVIOUSLY)?

4. IF YES, PLEASE GIVE REASON.

5. OTHER THAN THE BONE AND BALANCE CLASSES, DO YOU NORMALLY PARTAKE IN A REGULAR ROUTINE OF PHYSICAL ACTIVITIES (DURING MAY 2002 TO AUGUST 2002)?

6. IF YES, PLEASE DESCRIBE THE PROGRAM OR ROUTINE (INCLUDE TYPE OF EXERCISE, FREQUENCY, AND DURATION).

# May 2002 Reassessment

Name: _____

**FALL RECALL FORM**

**How many falls did you have in the month of March?**

**How many falls did you have in the month of April?**

**How many falls did you have in the month of May?**

**How many falls can you recall since the study started?**

**Did any of the fall result in injury?**

# Final Reassessment (August 2002)

Name:_____

## FALL RECALL FORM

How many falls did you have in the month of June?

How many falls did you have in the month of July?

How many falls did you have in the month of August?

How many falls can you recall since the study started?

Did any of the falls result in injury?

# Activity-specific Balance Confidence (ABC) Scale

For <u>each</u> of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale.  Answer all items even if there are activities you would not do or are unsure about.

0%    10%   20%   30%   40%   50%   60%   70%   80%   90%   100%

---

| Not | Completely |
| Confident | Confident |

How confident are you that you will not lose your balance or become unsteady when you.....

a.      walk around the house?_____%

b.      walk up and down stairs?_____%

c.      pick up a slipper from the floor?_____%

d.      reach at eye level?_____%

e.      reach while standing on your tiptoes?_____%

f.      stand on a chair to reach?_____%

g.      sweep the floor?_____%

h.      walk outside to nearby car?_____%

i.      get in and out of a car?_____%

j.      walk across a parking lot?_____%

k.      walk up and down a ramp?_____%

l.      walk in a crowded mall?_____%

m.      walk in a crowd or get bumped?_____%

n.      ride an escalator holding the rail?_____%

o.      ride an escalator not holding the rail?_____%

p.      walk on icy sidewalks?_____%

# MODIFIED CaMOS QUESTIONNAIRE

To begin the questionnaire I would like to ask you general questions about yourself.

1.     SOCIO-DEMOGRAPHIC INFORMATION

1.2     Date of Birth: _____/ _____/ _____     (Present age _____)
                      Day    Month    Year

1.3     In what country were you born?

1.8     How may years of school have you finished?  (Mark the highest grade completed)

        ❏ less than grade 9
        ❏ grades 9-13, without certificate or diploma
        ❏ high school certificate or diploma
        ❏ trades or professional certificate or diploma (CEGEP in Quebec)
        ❏ some university certificate or diploma
        ❏ university degree

1.9     What is your current employment status?

        ❏ Employed full time
        ❏ Homemaker (full time)
        ❏ Employed
        ❏ Disability
        ❏ Retired →     How old were you? _____ years
        ❏ Other (specify _____)

1.10    Do you live alone?        o Yes       o No

                                   Do you live with another adult?
                                   o Yes       o No

1.11    Do you have a particular doctor or clinic that
       you would call your regular doctor or clinic?      o Yes       o No

Now we'll review your past health.

2.    MEDICAL HISTORY

2.1    Has a doctor ever told you that you have any of the following conditions?

| | DIAGNOSIS | | | TREATMENT | | | |
|---|---|---|---|---|---|---|---|
| | Yes | No | DK | Yes | No | DK | N/A |
| Osteoporosis | | | | | | | |
| Rheumatoid arthritis | | | | | | | |
| Osteoarthritis | | | | | | | |
| Thyroid disease:<br>1 = Hyperthyroidism<br>2.= Hypothyroidism | | | | | | | |
| Liver disease | | | | | | | |
| Scoliosis | | | | | | | |
| Eating disorder | | | | | | | |
| Breast cancer | | | | | | | |
| Uterine cancer | | | | | | | |
| Inflammatory bowel disease | | | | | | | |
| Kidney stones | | | | | | | |
| Hypertension | | | | | | | |
| Heart attack | | | | | | | |
| Stroke<br>TIA (Transient Ischemic attack) | | | | | | | |
| Neuromuscular Disease<br>1 = Parkinson's Disease<br>2 = Multiple Sclerosis<br>3 = Other | | | | | | | |
| Diabetes:                    Age____<br>1 = Insulin Dependent<br>2 = Non Insulin Dependent | | | | | | | |
| Kidney disease | | | | | | | |

2.2     Which of the following surgeries have you had in the past?  How old were you?

|  | Yes | No | Age |
|---|---|---|---|
| Parathyroid |  |  |  |
| Thyroid |  |  |  |
| Stomach |  |  |  |
| Intestine |  |  |  |
| Gall Bladder |  |  |  |

2.4     Have you fallen in the past week?       o  Yes       o  No
                                                  ↓
                                                  How many times? ____

2.5     Have you fallen in the past month?       o  Yes       o  No
                                                  ↓
                                                  How many times? ____

Now I will ask you about any medicines you may have taken.

3.     DRUGS AND MEDICATIONS

3.1    Have you ever taken ay of the following medications daily for more than one month?

       If YES:  For approximately how may months total have you taken it?

| | Yes | No | Total # of Months Taken |
|---|---|---|---|
| Thyroid pills (Synthroid®) | | | |
| Dilantin (Seizure Pills) / Phenobarbital | | | |
| Tamoxifen (Nolvadex) | | | |
| Calcitonin (Calcimar) | | | |
| Didronel® / Etidronate | | | |
| Fosamax® / Alendronate | | | |
| Actonel® / Risedronate | | | |
| Fluoride (Fluatic) | | | |
| Diuretics – Thiaide / Other | | | |
| Laxatives | | | |
| Cortisone / Prednisone | | | |
|    1 = Oral | | | |
|    2 = Inhaled | | | |
| | | | FREQUENCY OF INJECTION |
|    3 = injection  a) Intravenous | | | |
|            b) Intramuscular, Subcutaneous | | | |

3.2    Current medications and or self administered supplements taken on a regular basis.

| Medications: From contents of medicine cabinet | | |
|---|---|---|
| NAME | DOSE | FREQUENCY |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

## 4. FRACTURES

4.1      Have you ever fractured any bones?    o Yes        o No   → Go to 5.1   If female

                               ↓

Complete the table below

(Refer to picture of body skeleton (if necessary)

Use the following trauma codes to indicate how it happened.

1 = severe trauma

2 = minimal trauma

3 = other disease

(See manual for definitions)

| Incident(s) | Trauma Code | Age (years) | BONE SITE | | | | | | | | | | OTHER | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BACK | | RIBS | | PELVIS | | FOREARM/ WRIST | | HIP | | Bone Site | | Bone Site | |
| | | | # | X | # | X | # | X | # | X | # | X | # | X | # | X |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

# = fracture

X = x-ray

In this section I would like to ask you questions that will help us understand how women's hormones relate to bone structure. We ask everyone these questions.

5.      REPRODUCTIVE HISTORY (FEMALES)

5.1     Before menopause, have you ever gone 3 months or more without a menstrual period?

> o Yes          o No
> ↓               ↳      Go to 5.2

> What was the longest single period of time without a menstrual flow?
> _____ months

> If you count all the periods you have missed throughout your
> Menstruating years, how many months would that be?  _____ months
> *(this question asks for the cumulative time)*

5.2     At what age did your menstrual periods stop.          _____ age

5.3     Have you had your uterus removed (hysterectomy)?
>              o Yes          o No
> ↓            ↳   At what age? _____years

5.4     Have you ever had one or both ovaries removed:

> ❑  Yes, one ovary removed at what age? _____
> ❑  Yes, both ovaries removed      at what age? _____

> (if ovaries were removed on separate occasions, write the age at which the second ovary was removed)

> ❑  Yes, do not know how many          at what age? _____
> ❑  No

5.5     Do you or did you ever take estrogen for menopause or for any other reason?

> ❑  Yes, currently                    o No
> ❑  Yes, but not now                  ↳      Go to 5.6
> ↓

What type(s)?

(Interviewers to show Ogen®, Premarin® pills, colours and doses
and Estraderm®, Estracomb® patches, sizes and doses)

o Pill

| Pill No. | Number of Days/month | Age Started | Age Stopped | Total number of Months taken |
|---|---|---|---|---|
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

o Patch

| Patch No. | Number of Days/month | Age Started | Age Stopped | Total number of Months taken |
|---|---|---|---|---|
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

o Injection       How many times/year?    _____
                  How many years?         _____

o Vaginal cream   How frequently?         _____

5.6 Do you or did you ever take Provera®, for menopause or for any other reason?

❑ Yes, currently        o No
❑ Yes, but not now        ↳     Go to 5.7
↓

What type(s)? (Interviewers to show Provera® pills, colours and doses)

o Pill

| Pill No. | Number of Days/month | Age Started | Age Stopped | Total number of Months taken |
|---|---|---|---|---|
|  |  |  |  | . |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

o Injection     How many times/year? _____
                 How many years?       _____

Now I will ask about your family history.

7.      FAMILY HISTORY

7.1     How many brothers and/or sisters do/did you have? (not adopted)

_____siblings        o do not know

7.2     I would like to ask about the following family members and their medical history

| Diagnosis | Parents | | | Siblings | | | | Children | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Yes | No | DK | Yes | No | DK | NA | Yes | No | DK | NA |
| Fracture |  |  |  |  |  |  |  |  |  |  |  |
| Osteoporosis |  |  |  |  |  |  |  |  |  |  |  |
| Osteoarthritis |  |  |  |  |  |  |  |  |  |  |  |
| Scoliosis |  |  |  |  |  |  |  |  |  |  |  |
| CVD, stroke, aneurysm, hypertension |  |  |  |  |  |  |  |  |  |  |  |
| Breast cancer |  |  |  |  |  |  |  |  |  |  |  |
| Ovarian cancer |  |  |  |  |  |  |  |  |  |  |  |
| Uterine cancer |  |  |  |  |  |  |  |  |  |  |  |

In this section I will ask you about diet, exercise programs and eating habits.

8.  PHYSICAL CHARACTERISTICS

8.1  What was your greatest adult height?    ____feet  ____inches  -or-  _____cm

o do not know

Now the questions I will ask will relate to the use of tobacco.

9.  TOBACCO

9.1  Have you ever used any of the following tobacco products daily for at least 6 months?

| | | |
|---|---|---|
| Cigarettes | o yes | o no |
| Pipes | o yes | o no |
| Cigars | o yes | o no |
| Chewing tobacco | o yes | o no | If NO to all: go to 9.3 |

9.2  Complete the following table for each product used.

➢ At what age did you begin to _____ daily? (for at least 6 months)
➢ Are you currently smoking? _____
➢ At what age did you stop? _____
➢ Approximately how many every day? (number of cigarettes, bowls of pipe tobacco, number of cigars, number of chews).._____
➢ Have you temporarily stopped _____and started again? (total up all periods and convert to years)

| | Age Started | Currently Smoking | | Age Stopped | Amount Per Day | Temporarily Stopped (Years) |
|---|---|---|---|---|---|---|
| | | Yes | NO | | | |
| Cigarettes | | | | | | |
| Pipe | | | | | | |
| Cigar | | | | | | |
| Chewing tobacco | | | | | | |

Name:_____

Date:_____

## QUESTIONNAIRE
## PHYSICAL ACTIVITY ASSESSMENT (7 DAYS)

WE WOULD LIKE TO KNOW ABOUT YOUR PHYSICAL ACTIVITY DURING THE PAST 7 DAYS, BUT FIRST, LET ME ASK YOU ABOUT YOUR SLEEP HABITS.

1. On average, how many hours did you sleep each night during the last 5 weekday nights (Sunday to Thursday)? _____ hours

2. On average, how many hours did you sleep each night of the last 5 Friday and Saturday nights? _____ hours

NOW I AM GOING TO ASK YOU ABOUT YOUR PHYSICAL ACTIVITY DURING THE PAST 7 DAYS, THAT IS, THE LAST 5 WEEKDAYS AND LAST WEEKEND, SATURDAY AND SUNDAY. WE ARE NOT GOING TO TALK ABOUT LIGHT ACTIVITIES SUCH AS SLOW WALKING, LIGHT HOUSEWORK, OR NON-STRENUOUS SPORTS SUCH AS BOWLING, ARCHERY OR SOFTBALL. PLEASE LOOK AT THIS LIST WHICH SHOWS SOME EXAMPLES OF WHAT WE CONSIDER MODERATE, HARD, OR VERY HARD ACTIVITIES.

(Interviewer shows subject the following list, and allows subject to read it over).

## *Examples of activities in each category*

Moderate Activity

> ➢ Occupational tasks: 1) delivering mail or patrolling on foot; 2) house painting; and 3) truck driving (making deliveries, lifting and carrying light objects).
> ➢ Household activities: 1) raking the lawn; 2) sweeping and mopping; 3) mowing the lawn with a power mower; and 4) cleaning windows.
> ➢ Sports activities (actual playing time): 1) brisk walking for pleasure or work; 2) golf, walking and pulling or carrying clubs; and 3) callisthenics exercises.

Hard Activity

> Occupational tasks: doing physical labour.
> Household tasks: scrubbing floors.
> Sports activities (actual playing time): 1) tennis doubles, 2) disco, square, or fold dancing.

Very Hard Activity

> Occupational tasks: very hard physical labour.
> Sports activities (actual playing time): 1) jogging or swimming; 2) singles tennis.

**First, let's consider moderate activities.**

1. **What activities did you do and how many total hours did you spend during the last 5 weekdays doing these moderate activities or others like them?  Please tell me to the nearest half hours (____ hours).**

2. **Last Saturday and Sunday, how many hours did you spend on moderate activities and what did you do?  (Probe:  Can you think of any other sports, jobs, or household activities that would fit into this category?) (____ hours).**

**Now, let's look at hard activities.**

3. **What activities did you do and how many total hours did you spend during the last 5 weekdays doing these hard activities or others like them?  Please tell me to the nearest half hour (____ hours).**

4. **Last Saturday and Sunday, how many hours did you spend on hard activities and what did you do?  (Probe:  Can you think of any other sports, jobs, or household activities that would fit into this category?) (____ hours).**

**Now, let's look at very hard activities**

5. What activities did you do and how many total hours did you spend during the last 5 weekdays doing these very hard activities or others like them?  Please tell me to the nearest half hour (_____ hours).

6. Last Saturday and Sunday, how many hours did you spend on very hard activities and what did you do? (Probe:  Can you think of any other sports, jobs, or household activities that would fit into this category?) (_____ hours).

Interviewer:  Please list below any activities reported by the subject which you don't know how to classify.  Flag this record for review and completion.

# The Robert Jones and Agnes Hunt Orthopaedic Hospital,
## Oswestry, Shropshire
### Department for Spinal Disorders

Name ............................................... Address ..............................................

Date of birth ...................... Age ............ .................................................. Date ...................

Occupation ........................................ ..................................................

.................................................. Hospital No ..............

How long have you had back pain? ............... Years ........... Months ........... Weeks

How long have you had leg pain? ............... Years ........... Months ........... Weeks

*Please read:*

This questionnaire has been designed to give the doctor information as to how your back pain has affected your ability to manage in everyday life. Please answer every section, and mark in each section only the *one box* which applies to you. We realise you may consider that two of the statements in any one section relate to you, but please just *mark the box which most closely describes your problem.*

### Section 1 — Pain Intensity
☐ I can tolerate the pain I have without having to use pain killers.
☐ The pain is bad but I manage without taking pain killers.
☐ Pain killers give complete relief from pain.
☐ Pain killers give moderate relief from pain.
☐ Pain killers give very little relief from pain.
☐ Pain killers have no effect on the pain and I do not use them.

### Section 2 — Personal Care (Washing, Dressing, etc)
☐ I can look after myself normally without causing extra pain.
☐ I can look after myself normally but it causes extra pain.
☐ It is painful to look after myself and I am slow and careful.
☐ I need some help but manage most of my personal care.
☐ I need help every day in most aspects of self care.
☐ I do not get dressed, wash with difficulty and stay in bed.

### Section 3 — Lifting
☐ I can lift heavy weights without extra pain.
☐ I can lift heavy weights but it gives extra pain.
☐ Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently positioned, eg on a table.
☐ Pain prevents me from lifting heavy weights but I can manage light to medium weights if they are conveniently positioned.
☐ I can lift only very light weights.
☐ I cannot lift or carry anything at all.

### Section 4 — Walking
☐ Pain does not prevent me walking any distance.
☐ Pain prevents me walking more than 1 mile.
☐ Pain prevents me walking more than ½ mile.
☐ Pain prevents me walking more than ¼ mile.
☐ I can only walk using a stick or crutches.
☐ I am in bed most of the time and have to crawl to the toilet.

### Section 5 — Sitting
☐ I can sit in any chair as long as I like.
☐ I can only sit in my favourite chair as long as I like.
☐ Pain prevents me sitting more than 1 hour.
☐ Pain prevents me from sitting more than ½ hour.
☐ Pain prevents me from sitting more than 10 mins.
☐ Pain prevents me from sitting at all.

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## Section 6 — Standing

- ☐ I can stand as long as I want without extra pain.
- ☐ I can stand as long as I want but it gives me extra pain.
- ☐ Pain prevents me from standing for more than 1 hour.
- ☐ Pain prevents me from standing for more than 30 mins.
- ☐ Pain prevents me from standing for more than 10 mins.
- ☐ Pain prevents me from standing at all.

## Section 7 — Sleeping

- ☐ Pain does not prevent me from sleeping well.
- ☐ I can sleep well only by using tablets.
- ☐ Even when I take tablets I have less than six hours sleep.
- ☐ Even when I take tablets I have less than four hours sleep.
- ☐ Even when I take tablets I have less than two hours sleep.
- ☐ Pain prevents me from sleeping at all.

## Section 8 — Sex Life

- ☐ My sex life is normal and causes no extra pain.
- ☐ My sex life is normal but causes some extra pain.
- ☐ My sex life is nearly normal but is very painful.
- ☐ My sex life is severely restricted by pain.
- ☐ My sex life is nearly absent because of pain.
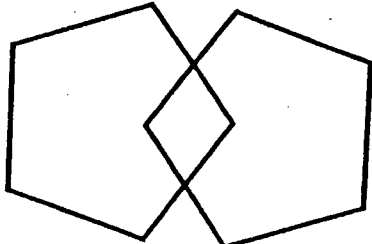- ☐ Pain prevents any sex life at all.

## Section 9 — Social Life

- ☐ My social life is normal and gives me no extra pain.
- ☐ My social life is normal but increases the degree of pain.
- ☐ Pain has no significant effect on my social life apart from limiting my more energetic interests, eg dancing, etc.
- ☐ Pain has restricted my social life and I do not go out as often.
- ☐ Pain has restricted my social life to my home.
- ☐ I have no social life because of pain.

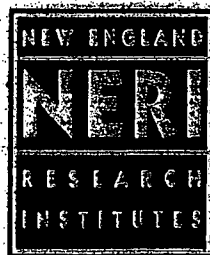## Section 10 — Travelling

- ☐ I can travel anywhere without extra pain.
- ☐ I can travel anywhere but it gives me extra pain.
- ☐ Pain is bad but I manage journeys over two hours.
- ☐ Pain restricts me to journeys of less than one hour.
- ☐ Pain restricts me to short necessary journeys under 30 minutes.
- ☐ Pain prevents me from travelling except to the doctor or hospital.

Comments _____

_____

# FOLSTEIN'S MINI MENTAL STATE[1]

| Max. Score | Score | |
|---|---|---|

## Orientation

**5 ( )** What is the (year) (season) (date) (day) (month)?

**5 ( )** Where are we? (country) (state) (town) (hospital) (floor)

## Registration

**3 ( )** Name 3 objects: 1 sec. to say each. Then ask the patient all 3 after you have said them. Give 1 point for each correct answer. Then repeat them until she learns all 3. Count trials and record.

**X    Trials**

## Attention and Calculation

**5 ( )** Serial 7s. 1 point for each correct. Stop after 5 answers. Alternatively spell 'world' backwards.

## Recall

**3 ( )** Ask for the 3 objects repeated above. Give 1 point for each.

## Language

**9 ( )**
- Name a pencil, and a watch (2 pts)
- Repeat the following: 'No ifs, ands or buts'.' (1 pt)
- Follow a 3-stage command: 'Take a paper in your right hand, fold it in half, and put it on the floor' (3 pts)
- Read and obey the following: CLOSE YOUR EYES (1 pt)
- Write a sentence (1 pt)
- Copy design (1 pt)

**Intersecting Pentagons**

**X    Total score**

## Instructions for Administration of Test

### Orientation:
(1) Ask for the date. Then ask specifically for parts omitted, e.g., 'Can you also tell me what season it is?'. *One point for each correct answer.* Ask in turn 'Can you tell me the name of this hospital' (town, country etc.). *One point for each correct.*

### Registration:
Ask the participant if you can test her memory. Then say the names of 3 unrelated objects, clearly and slowly, about one second for each. After you have said all 3, ask her to repeat them. This first repetition determines her score *(0-3)* but keep saying them until she can remember all 3, up to 6 trials. If she does not eventually learn all 3 recall cannot meaningfully be tested.

### Attention and Calculation:
Ask the participant to begin with 100 and count backwards by 7. Stop her after 5 subtractions (at 65). Score the total number of correct answers. If the participant prefers, she can spell the word 'world' backwards. Score is the number of letters in correct order.

### Recall:
Ask the participant to recall the words you previously asked her to remember. *Score 0-3.*

### Language:
*Naming:*
Show the participant a wristwatch and ask her what it is. Repeat for pencil. *Score 0-2.*
Repetition: Ask the participant to repeat the sentence after you. Allow only on trial. *Score 0 or 1.*
3-stage command. Give the participant a piece of plain blank paper and repeat the command. Score 1 point for each part correctly executed.
*Reading:*
On a blank piece of paper print the sentence 'Close your eyes' in letters large enough for the participant to see clearly. Ask her to read and to do what it says. Score 1 point only if she actually closes her eyes.
*Writing:*
Give the participant a blank piece of paper and ask her to write a sentence. Do not dictate a sentence, it is to be written spontaneously. It must contain a subject and a verb and be sensible. Correct grammar and punctuation are not necessary.
*Copying:*
On a clean piece of paper, draw intersecting pentagons, each side about 1 inch and ask her to copy it exactly as it is. All 10 angles must be present and 2 must intersect to score 1 point. Tremor and rotation are ignored.

# PHYSICAL ACTIVITY SCALE
# FOR THE ELDERLY

# ( P A S E )

# LEISURE TIME ACTIVITY

1.  Over the past 7 days, how often did you participate in sitting activities such as reading, watching TV or doing handcrafts?

[0.] NEVER    [1.] SELDOM    [2.] SOMETIMES    [3.] OFTEN
↓             (1-2 DAYS)     (3-4 DAYS)        (5-7 DAYS)
GO TO Q.#2    ↓              ↓                 ↓

---

1a.   What were these activities?

_____

1b.   On average, how many hours per day did you engage in these sitting activities?

[1.] LESS THAN 1 HOUR          [2.] 1 BUT LESS THAN 2 HOURS

[3.] 2-4 HOURS                 [4.] MORE THAN 4 HOURS

---

2.  Over the past 7 days, how often did you take a walk outside your home or yard for any reason? For example, for fun or exercise, walking to work, walking the dog, etc.?

[0.] NEVER    [1.] SELDOM    [2.] SOMETIMES    [3.] OFTEN
↓             (1-2 DAYS)     (3-4 DAYS)        (5-7 DAYS)
GO TO Q.#3    ↓              ↓                 ↓

---

2a.   On average, how many hours per day did you spend walking?

[1.] LESS THAN 1 HOUR          [2.] 1 BUT LESS THAN 2 HOURS

[3.] 2-4 HOURS                 [4.] MORE THAN 4 HOURS

---

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3. Over the past 7 days, how often did you engage in light sport or recreational activities such as bowling, golf with a cart, shuffleboard, fishing from a boat or pier or other similar activities?

[0.] NEVER     [1.] SELDOM     [2.] SOMETIMES     [3.] OFTEN
↓     (1-2 DAYS)     (3-4 DAYS)     (5-7 DAYS)
GO TO Q.#4     ↓     ↓     ↓

3a. What were these activities?

_____

3b. On average, how many hours per day did you engage in these light sport or recreational activities?

[1.] LESS THAN 1 HOUR     [2.] 1 BUT LESS THAN 2 HOURS

[3.] 2-4 HOURS     [4.] MORE THAN 4 HOURS

4. Over the past 7 days, how often did you engage in moderate sport and recreational activities such as doubles tennis, ballroom dancing, hunting, ice skating, golf without a cart, softball or other similar activities?

[0.] NEVER     [1.] SELDOM     [2.] SOMETIMES     [3.] OFTEN
↓     (1-2 DAYS)     (3-4 DAYS)     (5-7 DAYS)
GO TO Q.#5     ↓     ↓     ↓

4a. What were these activities?

_____

4b. On average, how many hours per day did you engage in these moderate sport and recreational activities?

[1.] LESS THAN 1 HOUR     [2.] 1 BUT LESS THAN 2 HOURS

[3.] 2-4 HOURS     [4.] MORE THAN 4 HOURS

5. Over the past 7 days, how often did you engage in strenuous sport and recreational activities such as jogging, swimming, cycling, singles tennis, aerobic dance, skiing (downhill or cross-country) or other similar activities?

[0.] NEVER  
↓  
GO TO Q.#6

[1.] SELDOM  
(1-2 DAYS)  
↓

[2.] SOMETIMES  
(3-4 DAYS)  
↓

[3.] OFTEN  
(5-7 DAYS)  
↓

5a. What were these activities?

_____

5b. On average, how many hours per day did you engage in these strenuous sport and recreational activities?

[1.] LESS THAN 1 HOUR          [2.] 1 BUT LESS THAN 2 HOURS

[3.] 2-4 HOURS                        [4.] MORE THAN 4 HOURS

6. Over the past 7 days, how often did you do any exercises specifically to increase muscle strength and endurance, such as lifting weights or pushups, etc.?

[0.] NEVER  
↓  
GO TO Q.#7

[1.] SELDOM  
(1-2 DAYS)  
↓

[2.] SOMETIMES  
(3-4 DAYS)  
↓

[3.] OFTEN  
(5-7 DAYS)  
↓

6a. What were these activities?

_____

6b. On average, how many hours per day did you engage in exercises to increase muscle strength and endurance?

[1.] LESS THAN 1 HOUR          [2.] 1 BUT LESS THAN 2 HOURS

[3.] 2-4 HOURS                        [4.] MORE THAN 4 HOURS

# HOUSEHOLD ACTIVITY

7. During the past 7 days, have you done any light housework, such as dusting or washing dishes?

   [1.] NO      [2.] YES

8. During the past 7 days, have you done any heavy housework or chores, such as vacuuming, scrubbing floors, washing windows, or carrying wood?

   [1.] NO      [2.] YES

9. During the past 7 days, did you engage in any of the following activities?

   Please answer <u>YES</u> or <u>NO</u> for each item.

   |     |                                                                              | <u>NO</u> | <u>YES</u> |
   |-----|------------------------------------------------------------------------------|-----------|------------|
   | a.  | Home repairs like painting, wallpapering, electrical work, etc.              | 1         | 2          |
   | b.  | Lawn work or yard care, including snow or leaf removal, wood chopping, etc.   | 1         | 2          |
   | c.  | Outdoor gardening                                                            | 1         | 2          |
   | d.  | Caring for an other person, such as children, dependent spouse, or an other adult | 1    | 2          |

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# WORK-RELATED ACTIVITY

10. During the past 7 days, did you work for pay or as a volunteer?

[1.] NO　　[2.] YES
　　　　　　　↓

10a. How many hours per week did you work for pay and/or as a volunteer?

_____ HOURS

10b. Which of the following categories best describes the amount of physical activity required on your job and/or volunteer work?

[1] Mainly sitting with slight arm movements. [**Examples:** office worker, watchmaker, seated assembly line worker, bus driver, etc.]

[2] Sitting or standing with some walking. [**Examples:** cashier, general office worker, light tool and machinery worker.]

[3] Walking, with some handling of materials generally weighing less than 50 pounds. [**Examples:** mailman, waiter/waitress, construction worker, heavy tool and machinery worker.]

[4] Walking and heavy manual work often requiring handling of materials weighing over 50 pounds. [**Examples:** lumberjack, stone mason, farm or general laborer.]