

**QUADRICEPS MUSCLE ACTIVITY IN FEMALE RUNNERS
WITH PATELLOFEMORAL PAIN SYNDROME**

by

DONNA LEE MACINTYRE

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Department of PHYSICAL EDUCATION

The University of British Columbia
1956 Main Mall
Vancouver, Canada
V6T 1Y3

Date Oct 3/86

ABSTRACT

The aim of this study was to determine if there was a difference in the surface EMG patterns of three of the quadriceps muscles (vastus medialis, vastus lateralis and rectus femoris) in female runners diagnosed with patellofemoral pain syndrome (PFPS) compared to the quadriceps activity of female runners free of knee pain and with normal lower extremity alignment.

Linear envelope EMGs from vastus medialis, vastus lateralis and rectus femoris, together with a footswitch signal, were digitally recorded as each subject ran on a treadmill at 12 km/h. Each stride period was normalized to 100%, and then the linear envelopes for ten trials from each muscle were ensemble averaged to achieve a mean ensemble for each muscle from each subject. Subsequently, the grand mean ensemble of each muscle for all of the subjects in each group was computed.

It was also the objective of this study to determine if there was a difference in the peak concentric and eccentric torques of the quadriceps and the hamstrings between the experimental group and the control group. The subjects were tested on an isokinetic dynamometer (KINCOM) through a range of 90° at an angular velocity of 200°/s.

The results showed no statistically significant differences between the groups for the peak EMG amplitudes. In fact when comparing the EMG patterns of activity between the two groups, the grand ensemble average of

the experimental group remained within \pm one standard deviation of the control group's mean EMG pattern. However, when individual subjects with PFPS were compared to the control group, there were periods in the gait cycle when the EMG amplitude was outside of \pm one standard deviation of the control group's mean.

When comparing the two groups for the peak concentric and eccentric torques of each muscle group, again the results were not statistically significant. The peak torques were also compared between groups as hamstrings/quadriceps ratios but found to be not significantly different. However, the mean concentric hamstrings/quadriceps ratio of the group with PFPS was found to be 1.02, which is outside of the range of values reported in the literature.

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INTRODUCTION

The dramatic increase in the popularity of exercise, and in particular running, in the past few decades has produced a need to understand the biomechanics of running so that elite athletes can improve their performances and clinicians can treat and perhaps prevent running injuries. This need is complicated by the fact that there may be more variability in the mechanics of running than in walking. Mann (1982) suggests that speed is one obvious variable which affects range of motion, muscle activity and joint forces in the lower extremity. However, if the running speed can be held constant by a treadmill, then a factor such as phasic muscle activity can be studied and compared between groups of subjects.

Our society's increased participation in physical activity has also resulted in an associated rise in overuse injuries. Malek and Mangine (1981) and Clement et al. (1981) have found from their review of clinical records that the most common site of injury is the knee and the most common clinical finding is patellofemoral pain syndrome (PFPS).

Patellofemoral pain syndrome has been described as a diffuse, poorly located pain around the patella which arises from abnormal tracking of the patella (Grana et al. 1984). Anatomical factors which have been identified as having some influence on the alignment of the patella are genu valgum, genu recurvatum, patella alta, a hypermobile patella, femoral neck anteversion, pronated feet, inefficiency of the vastus medialis muscle and/or hypertrophy of the vastus lateralis (Reynolds et al. 1983).

The electromyographic activity of the muscles of the knee, in particular the quadriceps have been studied in isometric contractions (Hallen and Lindahl, 1967; Lieb and Perry, 1971), in active and resisted muscle work (Pocock, 1963; Eloranta and Komi, 1981), during eccentric and concentric work (Komi, 1973), and during the last 30° of extension while weight-bearing (Reynolds et al, 1983). The next logical progression of muscle analysis particular to running has been to analyze the muscle activity during actual running using EMG (Elliott and Blanksby, 1979; Schwab et al. 1983; MacIntyre and Robertson, in press).

Improvements in electrical technology in the past few decades have made possible advancements in electromyographic analysis of gait. Through EMG studies of walking, a baseline of normal motor patterns has been established and specific abnormalities can be detected when compared to the norm (Winter, 1984). Utilizing these same techniques, it is also possible to study the patterns of muscle activity in running and to determine if there are observable abnormalities in certain clinical conditions.

Recent advancements in muscle testing techniques, in particular the development of an isokinetic dynamometer which can assess concentric and eccentric muscle strength, have made it possible to relate muscle strength results with functional activity. It has been shown by Winter (1983) that over one running stride the knee muscles absorb approximately three and a half times more energy than they generate, with the largest amount of eccentric activity in the quadriceps during stance phase. The importance of his findings during running relates to the use of the isokinetic

dynamometer and the need to be able to test and train muscles during concentric and eccentric contractions.

Purpose

The purpose of this study was to determine if there was a difference in the EMG patterns of the quadriceps in female runners with patello-femoral pain syndrome compared to a group of female runners free of knee pain and with normal lower extremity alignment.

Secondarily, this study compared the peak concentric and eccentric torque of the quadriceps and hamstrings at an angular velocity of 200°/s to see if there was a significant difference between those groups of subjects with and without patellofemoral pain syndrome.

METHODOLOGY

SUBJECTS

Twenty female recreational runners, aged 15-36 years, volunteered to take part in this study. Twelve of the subjects were placed in the control group as they had no complaints of knee pain, no previous lower extremity surgery or known musculoskeletal abnormalities, and 'normal' lower extremity alignment. They were evaluated by the physicians at U.B.C. Sports Medicine Clinic for Q-angle (Schamberger, 1983), rearfoot and forefoot alignment (James, 1979), the degree of pronation (James et al. 1978), leg length, and alignment at the knee (Lehmkuhl and Smith, 1983). Normal values were considered to be: Q-angle 15° or less, rearfoot and forefoot varus 4° or less, no overpronation, leg length discrepancy less than one centimeter and no genu recurvatum. These subjects were running at least 16 km/week (10 miles/week).

The experimental group consisted of eight subjects who had been diagnosed as having patellofemoral pain syndrome by the physicians at UBC Sports Medicine Clinic. They complained of right knee pain around the patella, and had the following lower extremity malalignment features: Q-angle 15° or more, rearfoot and forefoot alignment measures more than 4° and overpronation of the right foot when weight-bearing. Furthermore their leg length and alignment at the knee were assessed. These subjects were also running prior to the onset of pain.

EXPERIMENTAL PROCEDURE

Testing of Peak Torque

The subjects were tested on an isokinetic dynamometer (KINCOM) to determine the peak torque of their right quadriceps and hamstrings, during four concentric and eccentric contractions.

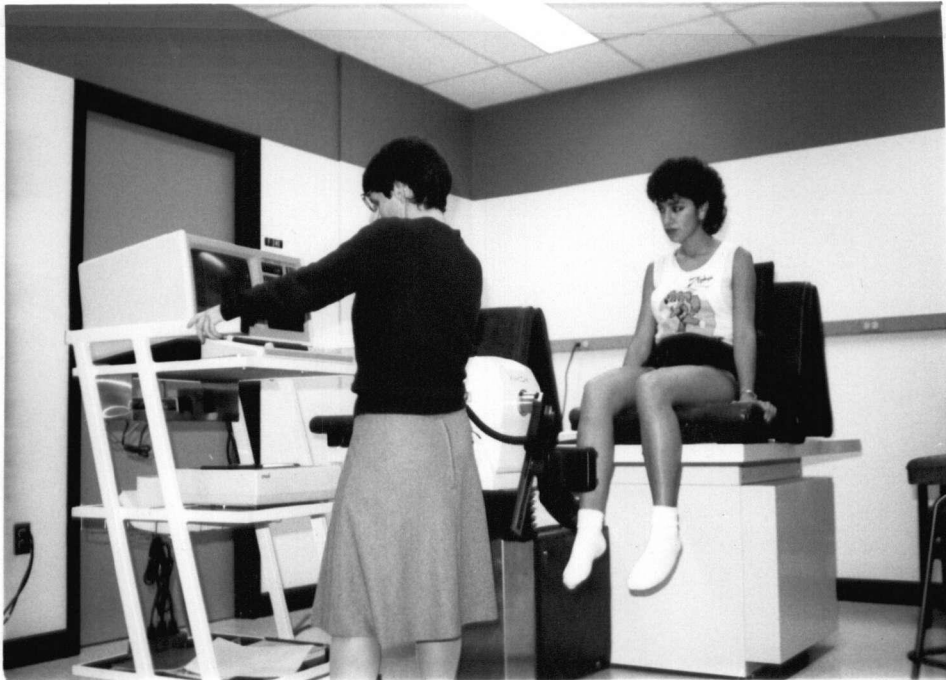


Illustration of a subject being tested for quadriceps strength on the KINCOM.

Each subject was instructed to sit with her back against the back support of the chair, the pelvis was stabilized by strapping, and the posterior aspect of the knee was positioned at the front of the chair.

Positioning of the subject's lower leg against the force arm of the machine followed the direction of Goslin and Charteris (1979). Subjects were instructed to grip the sides of the seat for support during the testing. During hamstrings testing additional stabilization was provided by strapping the thigh to the table.

The subjects were given standardized instructions and then four submaximal trials were performed before the maximal test. The range of motion for the knee movement was through an arc of 90° ($5^\circ - 95^\circ$) at a velocity of $200^\circ/\text{s}$, non-gravity corrected. Each test consisted of a concentric contraction and an eccentric contraction, thus, the subject had to concentrate on two consecutive contractions for each repetition. Each subject performed four maximal repetitions for each muscle group (quadriceps and hamstrings) with verbal encouragement.

EMG Measurement

The subjects ran on a treadmill, first at a speed that was 80% of their normal running pace and then for a second trial at 12 km/h (7.5 MPH) until 10 strides were collected by the computer. The first trial was used as a warm-up for the second run at 12 km/h.

Linear envelope EMG signals from the right vastus medialis, vastus lateralis and rectus femoris, together with a footswitch signal, were digitally recorded at 100 Hz each. Surface electrodes were placed over the motor points of each of the muscles (Delagi et al. 1975), with an interelectrode spacing of one centimeter. Preparation of the skin was according to the methods described by Basmajian (1979).

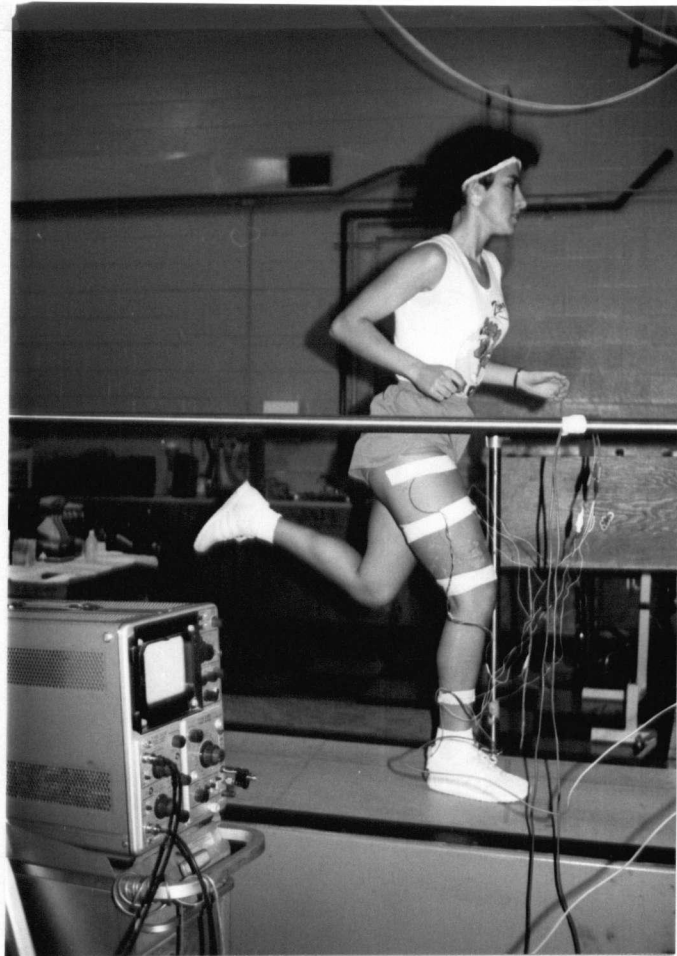


Illustration of a subject running on the treadmill with surface electrodes in place.

The bioamplifier (custom-made) had a frequency range of 20-1000 Hz, the gain was 1000, the input impedance was 10 megaohms and the common mode rejection ratio (CMRR) was greater than 100 dB. The amplifier utilized a second order band-pass filter (Winter, personal communication).

Each stride period was normalized to 100% and then ensemble averaged over the 10 trials for each muscle and for each subject by computer.

Standard deviations for each interval were also calculated. Subsequently grand ensemble averages for each muscle and for all of the subjects in each group were computed.

Statistical Analysis

A multivariate analysis (MANOVA) was done to determine if there was a difference between groups for the peak EMG amplitude from each muscle (vastus medialis, vastus lateralis and rectus femoris) during stance.

A second MANOVA analysis was performed to determine if there was a difference between groups for muscle strength (peak torques) in the quadriceps and hamstrings, both concentrically and eccentrically.

An analysis of the strength relationships between the quadriceps and hamstrings, as expressed as a ratio, was done by a t-test to determine if there was a difference between groups.

The level for significance of each analysis was set at $p < 0.05$.

A visual analysis of the EMG data was also included to determine if there was a difference of more than \pm one standard deviation in the phasic patterns of the muscle activity when the experimental group was compared to the control group. Furthermore, each individual's EMG profile was superimposed on the control group's grand ensemble average to determine if there were differences of more than \pm one standard deviation, in their EMG patterns.

RESULTS

Table I is a summary of the characteristics and clinical findings of the subjects in each group.

TABLE I
Descriptive Characteristics of the Subjects

	Control Group	Experimental Group
n	12	8
AGE (range)	20 - 32 years	15 - 36 years
HEIGHT (range)	155 cm - 175 cm	152.5 cm - 167.5 cm
WEIGHT (range)	53.2 - 63.6 kg	50 kg - 63.6 kg
KM/WEEK (range)	19 - 56	8 - 40
KNEE PAIN	No	Yes
Q-ANGLE	15° or less	15° or more
REARFOOT & FOREFOOT ALIGNMENT	4° or less	4° or more
OVERPRONATION (n)	4 mild	8

Figure 1 shows the grand ensemble averages of each muscle's EMG activity (V.M. - vastus medialis, R.F. - rectus femoris, V.L. - vastus lateralis) from the 12 subjects in the control group. The solid line represents the grand ensemble average while the dotted lines are \pm one standard deviation. One hundred percent of the gait cycle is from heel-strike to ipsilateral heel strike. Toe-off occurred between 29 and 45% of the cycle. The amplitude of the curves is measured in millivolts.

The grand ensemble averages of vastus medialis and rectus femoris represent 11 EMG profiles. There were ten EMG recordings obtained for the grand ensemble average of vastus lateralis.

Figure 2 represents the grand ensemble averages of each muscle for the eight subjects in the experimental group. Toe-off occurred between 30 and 50% of the gait cycle.

In the experimental group, there were a total of eight EMG profiles each for vastus medialis and vastus lateralis, while the number of recordings for rectus femoris was seven.

Figure 3 shows the grand ensemble average of each muscle from the experimental group superimposed on the results of the control group. The solid line is the grand ensemble average of the control group, the dotted lines represent \pm one standard deviation of the control group's mean, and the crossed line is the grand ensemble average of the experimental group.

FIGURE 1

GRAND ENSEMBLE AVERAGES OF THE CONTROL GROUP

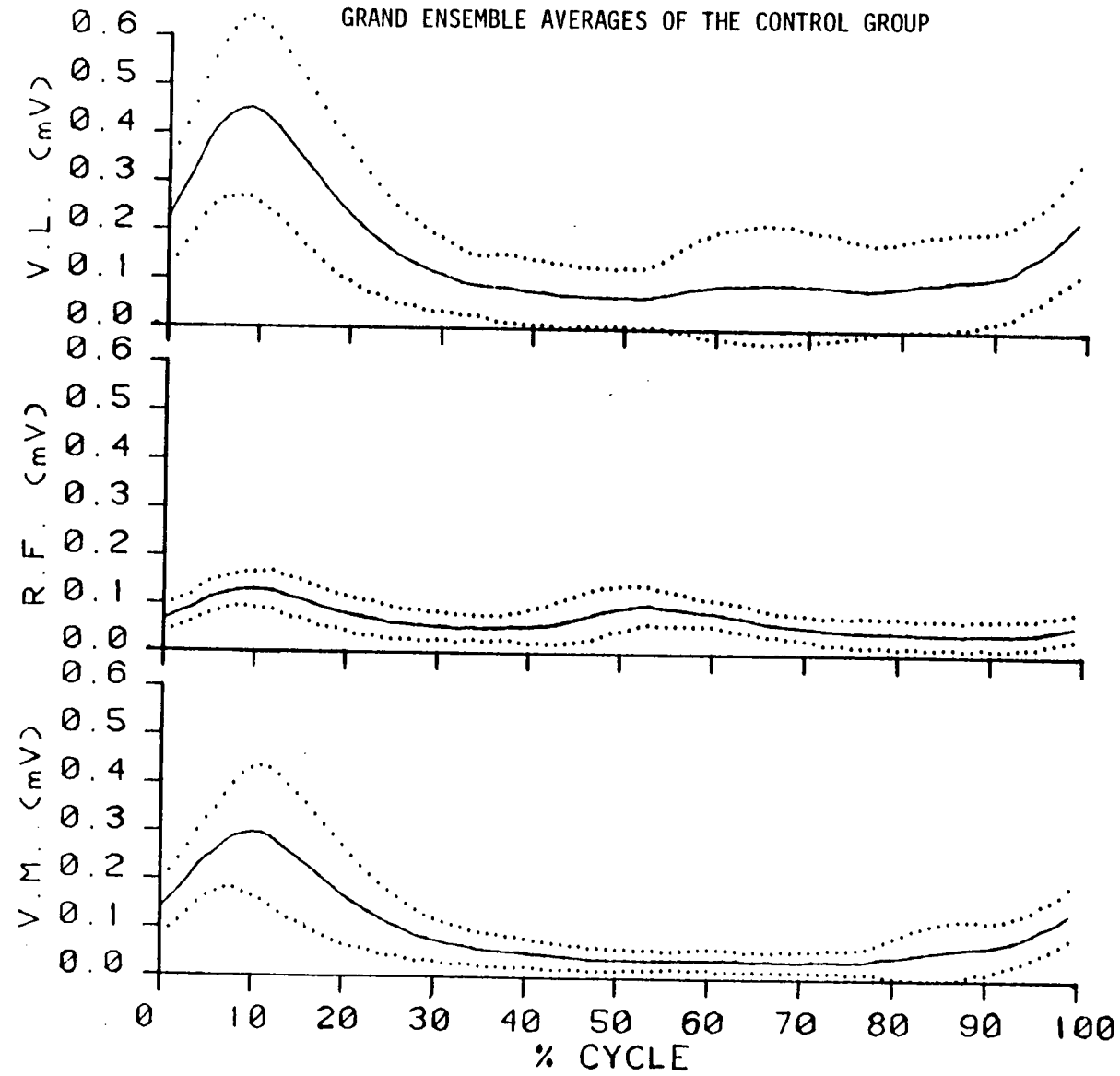


FIGURE 2
GRAND ENSEMBLE AVERAGES OF THE EXPERIMENTAL GROUP

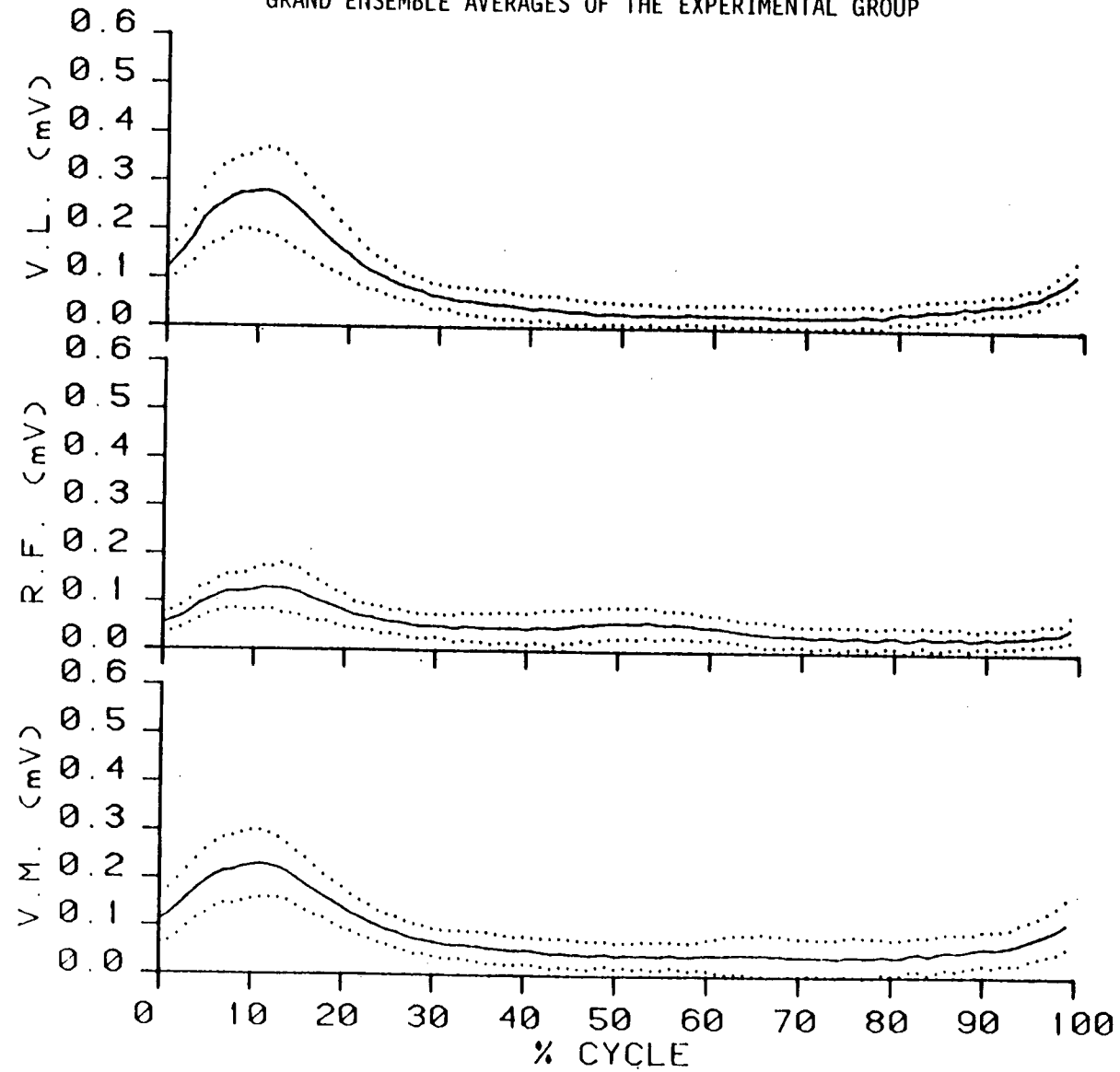
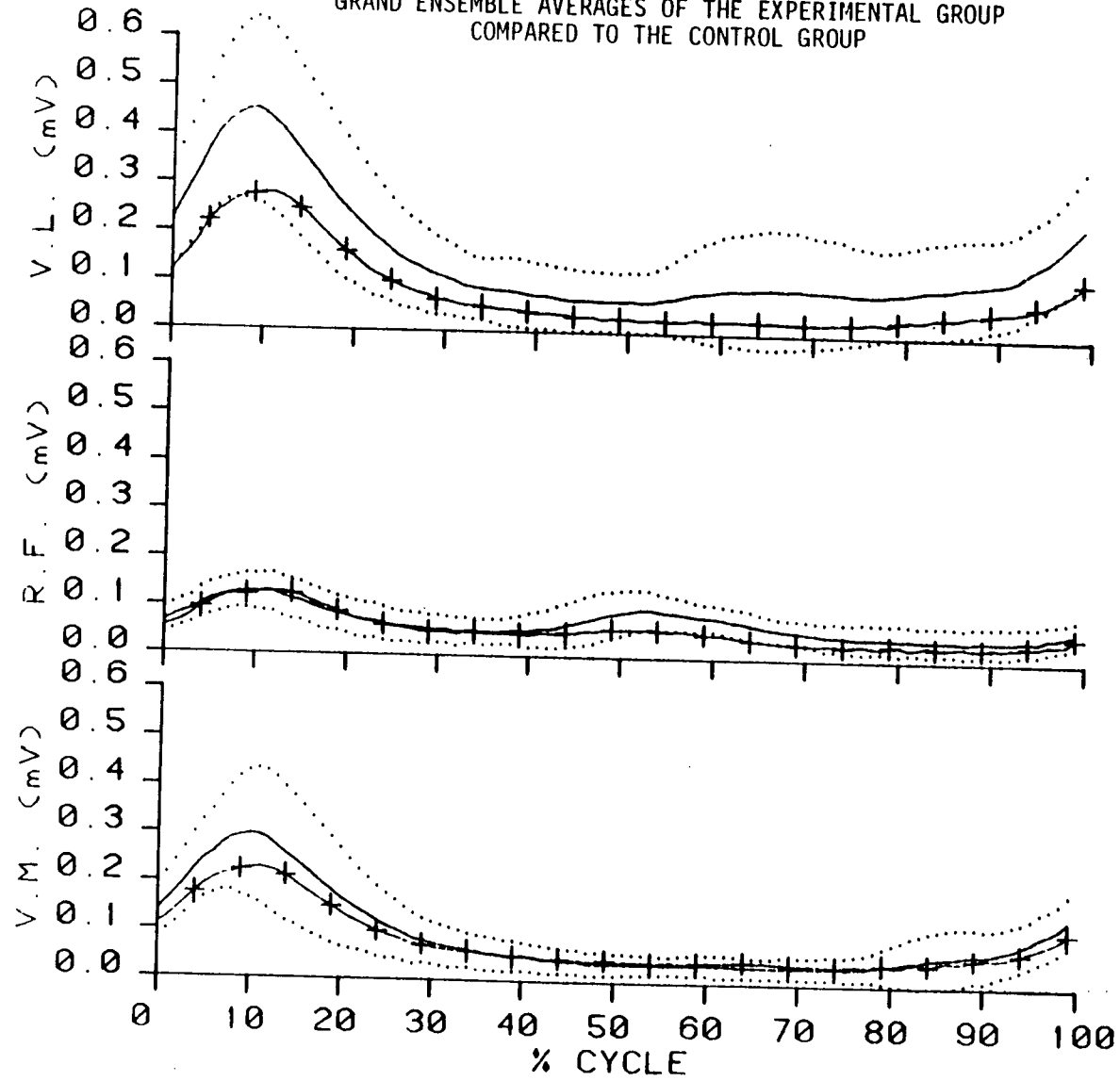


FIGURE 3

GRAND ENSEMBLE AVERAGES OF THE EXPERIMENTAL GROUP
COMPARED TO THE CONTROL GROUP



A multivariate analysis (MANOVA) of the peak EMG amplitudes of each muscle during stance showed no statistically significant difference between groups, and no statistically significant difference when the vastus medialis and the vastus lateralis were compared. However, the analysis did reveal a significant difference between the peak amplitudes of rectus femoris and the vastus lateralis and a significant difference between rectus femoris and the vastus medialis ($p < 0.05$).

TABLE II

Summary of Manova

EMG Peak Amplitude for Vastus Medialis,
Vastus Lateralis and Rectus Femoris

Control Group vs Experimental Group

df 1,13

Between Groups N.S. ($p = .114$)

Between Muscles

Vastus Lateralis \neq Rectus Femoris $p = .008$

Vastus Medialis \neq Rectus Femoris $p = .007$

Vastus Medialis \neq Vastus Lateralis N.S. ($p = .347$)

Subsequently, a t-test was performed for each muscle to determine if there would have been a significant difference between the control group and the experimental group peak EMG amplitudes if only one muscle had been tested in the experiment.

TABLE III
Summary of T-test

Vastus Medialis

Control Group	$\bar{x} = 309.18$	df = 17	t = 1.241	N.S.
Experimental Group	$\bar{x} = 238.87$			

Vastus Lateralis

Control Group	$\bar{x} = 457.40$	df = 16	t = 2.196	p < .025
Experimental Group	$\bar{x} = 289.87$			

Rectus Femoris

Control Group	$\bar{x} = 142.82$	df = 16	t = 0.244	N.S.
Experimental Group	$\bar{x} = 137$			

If vastus lateralis had been the only muscle tested there would have been a significant difference between the peak EMG amplitudes of the two groups (p < 0.05).

In Table IV the results of the muscle strength tests on the isokinetic dynamometer are summarized.

TABLE IV

Mean Peak Torque Values (± one standard deviation) at 200°/s for the

Right Quadriceps and Hamstrings

	Quadriceps		Hamstrings	
	Eccentric	Concentric	Eccentric	Concentric
Control Group	170 N.m	112.6 N.m	116.25 N.m	98.5 N.m
(n=12)	(<u>±</u> 50.33)	(<u>±</u> 22.27)	(<u>±</u> 26.53)	(<u>±</u> 21.85)
Experimental Group	139.4 N.m	95.1 N.m	111.4 N.m	93.6 N.m
(n=8)	(<u>±</u> 47.06)	(<u>±</u> 21.36)	(<u>±</u> 27.25)	(<u>±</u> 17.94)

Table V is a summary of the multivariate analysis of the mean peak torques when compared by groups, by muscles (quadriceps and hamstrings) and by contraction (eccentric and concentric).

TABLE V

Summary of Manova

Peak Torque Values - Group by Muscle by Contraction

df 1, 18

Between Groups	N.S. (p = .230)
Between Muscles	p = .001
Between Contractions	p < .001

Peak torque values were defined as the highest recorded value on any one of four repetitions of the muscle test, regardless of its position in the range of motion. There was no statistically significant difference between the groups for the peak torque values, although there was a significant difference between the peak torques of the hamstrings and the quadriceps when they were grouped by muscle. There was also a statistically significant difference between the peak torques of concentric and eccentric contractions.

Hamstrings/quadiceps (H/Q) ratios were calculated from the peak torque values of both the eccentric and concentric contractions. Table VI is a summary of the t-test to compare groups for each of the ratios.

TABLE VI

Summary of T-test

Peak Torque - Analysis By Ratios

H/Q RATIO CONCENTRIC

CONTROL GROUP $\bar{x} = .88$ $df = 18$ $t = -1.60$ N.S. ($p = .127$)

EXPERIMENTAL GROUP $\bar{x} = 1.02$

H/Q RATIO ECCENTRIC

CONTROL GROUP $\bar{x} = .73$ $df = 18$ $t = -1.06$ N.S. ($p = .304$)

EXPERIMENTAL GROUP $\bar{x} = .87$

There was no statistically significant difference between the groups for either the concentric or eccentric H/Q ratios.

Table VII is a summary of the number of deviations of the ensemble averages outside of \pm one standard deviation of the control group's mean, for the experimental group and the control group. In a normal (Gaussian) distribution 68.26% of the subjects' EMG profiles would lie within \pm one standard deviation and 15.87% would be above one standard deviation while 15.87% would be less than one standard deviation. To determine if the results of the control group followed a normal distribution, the EMG peak amplitudes during stance phase for all three muscles and swing phase for rectus femoris from each subject in the control group were compared to the mean EMG pattern \pm one standard deviation. Subsequently the same EMG amplitudes from each subject in the experimental group were compared to the control group's grand ensemble average \pm one standard deviation to determine if there were more deviations (outside \pm one standard deviation) in the EMG profiles of the group of subjects with patellofemoral pain syndrome than one would expect in a normal distribution.

TABLE VII
Deviations of the EMG Peak Amplitudes
Compared to the Control Group's Grand Ensemble Average

		Control Group	Experimental Group
Vastus medialis (stance phase)	within + 1 S.D.	6/11 *	6/8
	above 1 S.D.	3/11	
	below 1 S.D.	2/11	2/8
Rectus femoris (stance phase)	within + 1 S.D.	5/11	4/7
	above 1 S.D.	4/11	2/7
	below 1 S.D.	2/11	1/7
(swing phase)	within + 1 S.D.	6/11	2/7
	above 1 S.D.	3/11	
	below 1 S.D.	2/11	5/7
Vastus lateralis (stance phase)	within + 1 S.D.	6/10	4/8
	above 1 S.D.	2/10	
	below 1 S.D.	2/10	4/8

* Six subjects out of 11 remained within ± one standard deviation (S.D.).

DISCUSSION

Group Mean Muscle Activation Patterns

The results of the comparison of the grand ensemble averages of the quadriceps muscles (the vastus medialis, rectus femoris and the vastus lateralis) of subjects with patellofemoral pain syndrome to those subjects with normal lower extremity alignment and no knee pain, showed that the two groups had the same average patterns of muscle activity while running on a treadmill, varying only in regard to amplitude (Figure 3). The peak amplitude difference was not statistically significant (Table II) as the mean muscle patterns of the experimental group remained within \pm one standard deviation of the control group's mean.

The mean muscle patterns revealed that the largest amount of quadriceps activity occurred in early stance in both the control group and the experimental group. This burst of activity coincides with an energy absorbing phase by the knee extensors as they are contracting eccentrically to control knee flexion (Winter, 1983; Robertson and Taunton, 1982; Robertson, in press). Winter (1983) and Robertson (in press) have also reported from their power analyses of jogging and running, that from mid-stance until late-stance the quadriceps continue to be active but they are contracting concentrically to extend the knee.

From the EMG results of this study it would appear that the vastus medialis and vastus lateralis contribute most to the activity of the quadriceps during early stance, since rectus femoris showed less muscle activity at this time in the gait cycle. In their EMG study of the leg muscles during treadmill running, Elliott and Blanksby (1979) also

reported the vastus medialis and the vastus lateralis to have larger amplitudes during stance phase than rectus femoris, however, their results differed from this study in that they reported the vastus medialis to have the greatest peak amplitude while this study found the vastus lateralis to have the most EMG activity. It is not known why there may be the difference in the amplitudes of the two muscles between the two studies, as Elliott and Blanksby also had their female subjects (aged 20-28 years) run on a treadmill at approximately 12 km/h. The major difference between the studies is that Elliott and Blanksby used averaged integrated EMG as a form of processing while this study utilized linear envelope processing.

During swing phase, there was a second burst of activity in rectus femoris but no further activity in the vastus medialis or the vastus lateralis. Elliott and Blanksby (1979) also reported this second curve which they suggested is the muscle's contribution to hip flexion. The different muscle activation pattern of rectus femoris - having two bursts of activity during the gait cycle, while the vastus medialis and the vastus lateralis have only one - is because it is a two-joint muscle. Schwab et al. (1983) have reported that surface electrodes are not sensitive enough to depict the EMG pattern of specific muscles but rather are representative of the activity of a muscle group. However, the EMG profiles from this study indicate that there was a difference in the activity pattern of rectus femoris during running gait compared to the vastus medialis and the vastus lateralis. Furthermore, there was a statistically significant difference between the peak EMG amplitudes of

rectus femoris and the vastus lateralis ($p = 0.008$) and rectus femoris and the vastus medialis ($p = 0.007$) during stance phase (Table II).

In summary, a comparison of the average EMG patterns of the experimental group to the control group revealed the phasing of the patterns to be similar. Differences in the amplitude of the curves of the two groups were found; in particular the amplitudes of the muscle activity patterns of the experimental group were observed to be less than that of the control group. However, these differences were not found to be statistically significant. This lack of a statistical difference may have resulted for different reasons. It may be that the differences in the muscle activation patterns between a 'normal' group of runners and a group of runners with PFPS are too subtle for the EMG to record even though the literature has suggested that there may be quadriceps weakness associated with PFPS, and more specifically weakness of vastus medialis (LeVeau & Rogers, 1980; Fox, 1975). Richards et al. (1985) have suggested that the altered gait of a severely disabled person will result in changes in the timing of the EMG patterns, however, the gait of patients with PFPS is not usually severely affected by their condition, and in the case of the subjects in this study many were still running.

It may also be that averaging the EMG patterns of individuals with a clinical condition only averages the differences of each of those subjects. Clinically it would be more beneficial to analyze each individual's results compared to a 'norm' to determine how or if the patient differs, and then treatment could be directed to correcting the problem.

Peak Concentric and Eccentric Torque Values of the Knee Extensor and Flexor Muscles

The results show that there was no statistically significant difference between the subjects with PFPS and the group of subjects free of knee pain and with normal alignment when the mean peak concentric and eccentric torque values were compared, for both the right quadriceps and hamstrings.

To date there have been few studies of the quadriceps and hamstrings torques at certain velocities in young women, and of these few they have only investigated concentric muscle activity. Wyatt & Edwards (1981) studied 50 non-athletic female subjects aged 25 - 34 years, at three angular velocities. They found at 180°/s that the group's mean peak torques were 57 ft-lbs. (77 N.m) for the quadriceps and 45 ft-lb (61 N.m) for the hamstrings. Dibrezzo et al. (1985) studied 241 non-athletic females aged 18 - 28 years but only at 60°/s. Berg et al. (1985) studied 13 female college basketball players and found their mean peak torques to be 78.7 ft-lb (107 N.m) for the right knee extensors and 56.3 ft-lb (76 N.m) for the right knee flexors at 180°/s. Richards (1981) studied 19 females whose ages ranged from 21 - 60 years whose activity levels were not stated, and she reported their mean peak torque for the quadriceps to be 80.9 N.m and for the hamstrings to be 48.1 N.m, at 180°/s. All of these studies used the Cybex II isokinetic dynamometer, and in each case the subjects were tested in sitting with a back support.

Each group of investigators also presented their results as a hamstrings/quadriceps ratio (H/Q ratio) - that is the peak torque of

concentric knee flexion divided by the peak torque of concentric knee extension. In this case at an angular velocity of $180^{\circ}/s$ Wyatt & Edwards reported a ratio of .79, Berg et al. reported .72 and Richards found a ratio of .60. The difference in the ratio's may be due to the different activity levels and the different age groups of the subjects in each study.

The testing for this study was performed on a KINCOM at an angular velocity of $200^{\circ}/s$ with the subjects seated and supported by a backrest. The gravity correction option was not used so that comparisons could be made to other studies. Those females who were running a minimum of 16 km week (10 miles/week) and who were free of lower extremity abnormalities and pain had a concentric mean peak torque of 112.6 N.m for the right quadriceps and 98.5 N.m for the right hamstrings. The mean H/Q ratio of this group was .88.

Nosse (1982) reviewed 50 reports of hamstrings/quadriceps ratios and found that the ratios varied from .43 - .90, under a variety of conditions. He suggested that it is necessary to consider the angular velocity of the test, the testing position, the equipment used and the population being investigated before comparing or generalizing from one study to another. Appen & Duncan (1986) elaborate further on subject characteristics, suggesting that sex, age, activity level and type of activity also influence the torque values. They have found in their research that at high concentric velocities ($300^{\circ}/s$), there was a significant difference between types of competitors, which may indicate that fibre type composition or fibre size is a factor in peak torque

values. Furthermore, they noted that gravity affects the measured torques. At each of four angular velocities ($60^{\circ}/s$, $180^{\circ}/s$, $240^{\circ}/s$ and $300^{\circ}/s$) the gravity corrected peak extensor torques were increased compared to the nongravity corrected torques, while the gravity corrected flexor peak torques decreased. These differences resulted in a significant difference between the H/Q ratios corrected and not corrected for gravity, with the gravity corrected torques lower.

As more studies are published it becomes apparent that there is a need for baseline or normal data from well delineated populations with well defined testing protocols, so that comparisons can be made. Comparing the results of this study's group of female runners (without PFPS) to the non-athletic females in Wyatt & Edward's study, the peak torque values for the runners were higher for both the quadriceps and hamstrings, as would be expected comparing active and non-active populations. In Berg & coworkers' study the female basketball players had a mean H/Q ratio less than the recreational runners from this study, which was demonstrated by the fact that the mean peak extensor torques were nearly the same (107 N.m compared to 112.6 N.m respectively) but the mean peak flexor torques had a greater spread between them. The mean peak flexor torque of the basketball players was less than that of the runners (76 N.m compared to 98.5 N.m). This comparison is indicative of differences in types of activity and activity levels. However, one can not rule out that types of equipment (i.e., - Cybex vs Kincom) may also be contributing to the differences.

Another purpose of establishing normative data is so that comparisons can be made to clinical findings. Campbell and Glenn (1982) studied the results of rehabilitation in male and female patients with chondromalacia, and other knee problems, and reported the mean peak torques of the knee muscles of the involved leg before treatment to be less than the same muscles of the non-involved limb. Richards et al. (1985) compared the mean peak knee extensor and flexor torques of rheumatoid arthritic patients (functional class II) to a 'normal' group, and found significant differences between the two groups. The results of this study have shown the concentric mean peak torques of the quadriceps and hamstrings in those patients with PFPS (Table IV) not to be significantly different from the control group (Table V). The results of these studies indicate that the cause of pain and the activity level allowed by a disability or dysfunction of the musculoskeletal system are important considerations in analyzing test results. One would expect patients with the disabling disease of rheumatoid arthritis to have significantly less muscle strength compared to a control group, while those patients with PFPS are still relatively active although they may not be running as a form of exercise. This brings forth the need to determine what is clinically significant for each condition.

Goslin and Charteris (1979) believe that the H/Q ratio could be an indicator of clinical abnormality at the knee or an indicator of the potential for injury. This ratio is speed-specific, as the angular velocity increases the differences between the concentric peak torques of the quadriceps and hamstrings decreases (Wyatt and Edwards, 1981). The

concentric H/Q ratio from this study of .88 for the control group at an angular velocity of $200^{\circ}/s$, suggests that the peak torque differences between the two muscle groups is not great.

The concentric H/Q ratio from those subjects with PFPS was 1.02 (Table VI) which was not statistically different from the control group but which is outside of the range reported by Nosse (1982). This H/Q ratio suggests that on the average the subjects with PFPS had similar strength in the hamstrings as in the quadriceps.

The only eccentric investigation of isokinetic muscle activity found in the literature is that by Komi (1973) during which he studied the elbow flexors. He found that as velocity of contraction increased, the concentric force decreased and the eccentric force increased. From the results of this study, at $200^{\circ}/s$, the eccentric mean peak torques for both the control group and the experimental group were higher than the concentric mean peak torques for the same muscles (Table IV). The results suggest that further study is necessary to determine if a similar force-velocity relationship exists in clinical conditions (such as PFPS) as well as in the muscles of normal healthy subjects.

Although there are no other studies which have reported eccentric peak torques of the quadriceps and hamstrings with which to compare, it is valuable to note the findings from this study for the control group and the experimental group (Table IV) so that future comparisons can be made. Similarly there has been no literature on the eccentric H/Q ratio. There was not a statistically significant difference between the two groups when comparing eccentric H/Q ratios in this study, however, as

previously stated it is useful to note the ratios (Table VI) for future comparisons.

It is interesting to note from the results that the concentric and eccentric mean peak torque values of the hamstrings for both subject groups are closer together while the mean peak torques of each group for the quadriceps are much farther apart (Table IV).

In summary, the results of our isokinetic testing have revealed that -

- i) the mean concentric H/Q ratio (1.02) of those subjects with PFPS was above the range that has been reported in the literature.
This abnormally high ratio suggested that the mean peak torque of the hamstrings was nearly the same as the mean peak torque of the quadriceps.
- ii) at an angular velocity of $200^{\circ}/s$ the concentric and eccentric H/Q ratios were different, due to the fact that the concentric and eccentric mean peak torques of the hamstrings were closer together while the concentric and eccentric mean peak torques of the quadriceps had a greater spread between them.

iii) when considering clinical findings compared to norms, it appears that clinical significance differs from statistical significance, and that each condition may have a different level of significance depending upon pain, musculoskeletal involvement and degree of disability.

CONCLUSIONS

The results of this study have shown that:

1. From a visual analysis of the mean EMG profiles of the experimental group superimposed on the control group's mean EMG pattern \pm one standard deviation, the mean muscle activity of the vastus medialis, rectus femoris and the vastus lateralis was similar (within \pm one standard deviation) for subjects with patellofemoral pain syndrome compared to subjects free of knee pain and with normal lower extremity alignment, during treadmill running. Additionally, a multivariate analysis (MANOVA), of the peak EMG amplitudes revealed that there was not a significant difference between the two groups.
2. The mean EMG pattern for rectus femoris from both groups was different from the vastus medialis and the vastus lateralis, in that rectus femoris had a burst of activity during stance phase and a second burst of activity during swing, while the vastus medialis and the vastus lateralis had only one burst of activity during stance phase. Furthermore, there was a statistically significant difference in the peak EMG amplitudes of rectus femoris compared to the vastus medialis and rectus femoris compared to the vastus lateralis during stance phase.
3. There was no statistically significant difference between the subjects with and without patellofemoral pain syndrome when their

mean peak concentric and eccentric torque values were compared for the right hamstrings and quadriceps. Similarly a t-test of the peak torque values expressed as a hamstrings/ quadriceps ratio showed that there was not a significant difference between the groups. However, the mean concentric H/Q ratio from the subjects with PFPS was 1.02 which is outside of the normal range which has been reported in the literature.

RECOMMENDATIONS

Based on the understanding gained as a result of this study, the following recommendations are suggested for future investigations.

1. The size of the control group must be greater so that the mean EMG profile \pm one standard deviation from each muscle would have less variability and better represent a normal distribution.
2. Activities such as ascending or descending stairs or squatting may reveal greater differences in the EMG profiles of those subjects with patellofemoral pain syndrome compared to a control group, as the joint reaction forces through the patellofemoral joint are known to be high during those activities and patients often complain of pain during those activities.
3. By recording the EMG activity of the muscles simultaneously with the muscle testing and then recording the muscle activity during a functional activity without removing the electrodes, the investigator would be able to determine the percentage of muscle activity during activity compared to a maximal strength test.
4. Further study may involve pre-treatment and post-treatment EMG and muscle strength evaluation of patients with patellofemoral pain syndrome.

REFERENCES

- Anderson, J.E., ed. Grant's Atlas of Anatomy. VIII Edition. Williams and Wilkins Co., Baltimore. 1983.
- Appen, E.L., Duncan, P.W. Strength relationship of the knee musculature: Effects of gravity and sport. J. of Orthopaedic and Sports Physical Therapy. 7: 232-235. 1986.
- Basmajian, J.V. Re-education of vastus medialis: A misconception. Archives of Physical Medicine and Rehabilitation. 51: 245-247. 1970.
- Basmajian, J.V. Muscles Alive. IV Edition. The Williams & Wilkins Co., Baltimore. 1979.
- Berg, K., Blanke, D., Miller, M. Muscular fitness profile of female college basketball players. J. of Orthopaedic and Sports Physical Therapy. 7: 59-64. 1985.
- Bouisset, S., Maton, B. Quantitative relationship between surface EMG and intramuscular electromyographic activity in voluntary movement. American Journal of Physical Medicine. 51: 285-295. 1972.
- Cailliet, R. Knee Pain and Disability. F.A. Davis & Co., Philadelphia. 1974.
- Campbell, D.E., Glenn, W. Rehabilitation of knee flexor and knee extensor muscle strength in patients with meniscectomies, ligamentous repairs, and chondromalacia. Physical Therapy. 62: 10-15. 1982.
- Clement, D.B., Taunton, J.E., Smart, G.W., McNicol, K.L. A survey of overuse running injuries. The Physician and Sports Medicine. 9: 47-58. 1981.
- Delagi, E.F., Perotto, A., Iazetti, J., Morrison, D. Anatomic Guide for the Electromyographer. Charles C. Thomas. Springfield. 1975.
- Dibrezzo, R., Gench, B.E., Hinson, M.M., King, J. Peak torque values of the knee extensor and flexor muscles of females. J. of Orthopaedic and Sports Physical Therapy. 7: 65-68. 1985.
- Elliott, B.C., Blanksby, B.A. The synchronization of muscle activity and body segment movements during a running cycle. Medicine and Science in Sport. 11: 322-327. 1979.

- Eloranta, V., Komi, P. Function of the quadriceps femoris muscle under the full range of forces and differing contraction velocities of concentric work. Electromyography and Clinical Neurophysiology. 21: 419-431. 1981.
- Ficat, R.P., Hungerford, D.S. Disorders of the Patellofemoral Joint. The Williams & Wilkins Co., Baltimore. 1977.
- Fox, T.A. Dysplasia of the quadriceps mechanism. Surgical Clinics of North America. 55: 199-226. 1975.
- Goslin, B.R., Charteris, J. Isokinetic dynamometry: Normative data for clinical use in lower extremity (knee) cases. Scandinavian Journal of Rehabilitation Medicine. 11: 105-109. 1979.
- Grana, W.A., Hinkley, B., Hollingsworth, S. Arthroscopic evaluation and treatment of patellar malalignment. Clinical Orthopaedics. 186: 122-128. 1984.
- Hallen, L.G., Lindahl, O. Muscle function in knee extension. Acta Orthopaedica Scandinavia. 38: 434-444. 1967.
- Hughston, J.C. Subluxation of the patella. J. of Bone & Joint Surgery. 50: 1003-1026. 1968.
- International Society of Electrophysiological Kinesiology. Units, Terms, and Standards in the Reporting of EMG Research. August 1980.
- James, S.L. Chondromalacia of the patella in the adolescent. In The Injured Adolescent Knee. p. 205-250. Edited by J.C. Kennedy. The Williams & Wilkins Co., Baltimore. 1979.
- Kessler, R.M., Hertling, D. Management of Common Musculoskeletal Disorders. p. 205-250. Harper & Row, Philadelphia. 1983.
- Knapik, J., Ramos, M. Isokinetic and isometric torque relationships in the human body. Archives of Physical Medicine and Rehabilitation. 61: 65-67. 1980.
- Komi, P.V. Measurement of the force - velocity relationship in muscle under concentric and eccentric contractions. In Biomechanics III. p. 224-229. Karger. Basel. 1973.
- Komi, P., Buskirk, E. Reproducibility of electromyographic measurements with inserted wire electrodes and surface electrodes. Electromyography. 10: 357-367. 1970.

- Komi, P.V. Relationships between muscle tension, EMG and velocity of contraction under concentric and eccentric work. In New Developments in Electromyography and Clinical Neurophysiology. p. 596-606. Edited by J.E. Desmedt. Karger, Basel. 1973.
- Lehmkuhl, L.D., Smith, L.K. Brunnstrom's Clinical Kinesiology. Edition 4. F.A. Davis, Philadelphia. 1983.
- LeVeau, B.F., Bernhardt, D.B. Developmental biomechanics. Physical Therapy. 64: 1874-1882. 1984.
- Lieb, F.J., Perry, J. Quadriceps function. An electromyographic study under isometric conditions. J. of Bone and Joint Surgery. 53A: 749-758. 1971.
- MacIntyre, D., Robertson, D.G.E. EMG profiles of the knee muscles during treadmill running. In Biomechanics X. In press.
- Malek, M.M., Mangine, R.E. Patellofemoral pain syndromes: A comprehensive and conservative approach. J. of Orthopaedic and Sports Physical Therapy. 2: 108-116. 1981.
- Mann, R.A. Biomechanics of running. Prevention and Treatment of Running Injuries. C.B. Slack, New Jersey. 1982.
- Mariani, P.P., Caruso, I. An electromyographic investigation of subluxation of the patella. J. Bone and Joint Surgery. 61-B: 169-171. 1979.
- Moffroid, M., Whipple, R., Hofkosh, J., Lowman, E., Thistle, H. A study of isokinetic exercise. Physical Therapy. 49: 735-746. 1969.
- Murray, M.P., Gardner, G.M. Mollinger, G.M. Sepic, S.B. Strength of isometric and isokinetic contractions. Physical Therapy. 60: 412-419. 1980.
- Nosse, L.J. Assessment of selected reports on the strength relationship of the knee musculature. J. of Orthopaedic and Sports Physical Therapy. 4: 78-84. 1982.
- Perrine, J. Isokinetic exercise and the mechanical energy potentials of muscle. J. of Health and Physical Education 39: 40-44. 1968.
- Perry, J. EMG - Surface vs. wire. Physical Therapy. 61: 925-927. 1981.
- Perry, J. Easterday, C., Antonelli, D. Surface vs intramuscular electrodes for electromyography of superficial and deep muscles. Physical Therapy. 61: 7-15. 1981.

- Pocock, G. Electromyographic study of the quadriceps during resistive exercise. Physical Therapy. 43: 427-434. 1963.
- Reynolds, L., Levin, T.A., Medeiros, J.M., Adler, N.S., Hallum, A. EMG activity of the vastus medialis oblique and the vastus lateralis in their role in patellar alignment. American Journal of Physical Medicine. 62: 61-70. 1983.
- Richards, C.L., Dynamic strength characteristics during isokinetic knee movements in healthy women. Physiotherapy Canada. 33: 141-150. 1981.
- Richards, C.L., Wessel, J., Malouin, F. Muscle activation patterns in gait of rheumatoid arthritic patients. Physiotherapy Canada. 37: 220-228. 1985.
- Robertson, D.G.E. Functions of the leg muscles during stance phase in running. In Biomechanics X. In press.
- Robertson, D.G.E., Taunton, J.E. Power characteristics of leg muscles during stance phase of running. Proceedings of the Second Biannual Conference of the Canadian Society for Biomechanics, 1982.
- Schamberger, W. Orthotics for athletes: Attacking the biomechanical roots of injury. Canadian Family Physician. 29: 1670-1680. 1983.
- Schwab, G.H., Moynes, D.R., Job, F.W., Perry, J. Lower extremity electromyographic analysis of running gait. Clinical Orthopaedics. 176: 166-170. 1983.
- Taunton, J.E., Clement, D.B., Smart, G.W., Wiley, J.P., McNicol, K.L. A triplanar electrogoniometer investigation of running mechanics in runners with compensatory overpronation. Canadian Journal of Applied Sport Sciences. 10: 104-115. 1985.
- Vredenburg, J., Rau, G. Surface electromyography in relation to force, muscle length and endurance. In New Developments in Electromyography and Clinical Neurophysiology. p. 607-622. Edited by J.E. Desmedt. Karger. Basel. 1973.
- Wiberg, G. Roentgenographic and anatomic studies on the femoropatellar joint. Acta Orthopaedica Scandinavica. 12: 319-410. 1941.
- Wild, J., Franklin, T., Woods, G. Patellar pain and quadriceps rehabilitation. American Journal of Sports Medicine. 10: 12-15. 1982.
- Winter, D.A., Biomechanics of Human Movement. John Wiley & Sons, New York. 1979.

Winter, D.A. Movements of force and mechanical power in jogging. J. of Biomechanics. 16: 91-97. 1983.

Winter, D.A. Pathologic gait diagnosis with computer-averaged electromyographic profiles. Archives of Physical Medicine and Rehabilitation. 16: 91-97. 1984.

Wyatt, M.P., Edwards, A.M. Comparison of quadriceps and hamstring torque values during isokinetic exercise. J. of Orthopaedic and Sports Physical Therapy. 3: 48-56. 1981.

APPENDIX 1

TABLE VIII

Clinical Characteristics of the Control Group Subjects

	CS	CR	GG	JF	LS	MR	PB	PW	SL	SO	SP	VA
Age (years)	20	22	20	21	27	32	25	21	29	23	25	26
Height (cm)	155	155	167.5	160	165	170	172.5	160	165	175	170	167.5
Weight (kg)	60.9	54.5	58.1	54.5	60	53.6	56.4	53.2	63.6	63.6	54	53.2
Km/wk running	19	24	56	16	56	24	32	24	40	40	19	48
Knee pain	no	no	no	no	no	no	no	no	no	no	no	no
Knee alignment	valgus	valgus	valgus	varus	varus	varus	varus	varus	varus	valgus	varus	valgus
Q-angle	12°	12°	10°	12°	12°	15°	15°	14°	12°	13°	12°	10°
Rearfoot varus alignment	< 4°	< 4°	< 4°	< 4°	< 3°	< 4°	< 4°	< 4°	< 4°	< 4°	< 4°	< 4°
Forefoot varus alignment	< 4°	< 4°	< 4°	< 4°	< 3°	< 4°	< 4°	< 4°	< 2°	< 3°	< 3°	< 4°
Overpronation	no	mild	no	mild	mild	no	no	mild	no	no	no	no
Leg-length	equal	equal	equal	R<L 1cm*	equal	equal	equal	equal	equal	equal	equal	equal

* right leg shorter than left by one centimeter

Individual Ensemble Averages from the Control Group

Figures 4 to 15 are the ensemble averages of the linear envelope EMG of vastus medialis (V.M.), rectus femoris (R.F.) and vastus lateralis (V.L.) for each subject in the control group. The solid line represents the ensemble average while the dotted lines are \pm one standard deviation. One hundred percent of the gait cycle is from heel-strike to ipsilateral heel-strike. Toe-off is indicated by \blacktriangle . The amplitude of the curves is measured in millivolts.

FIGURE 4

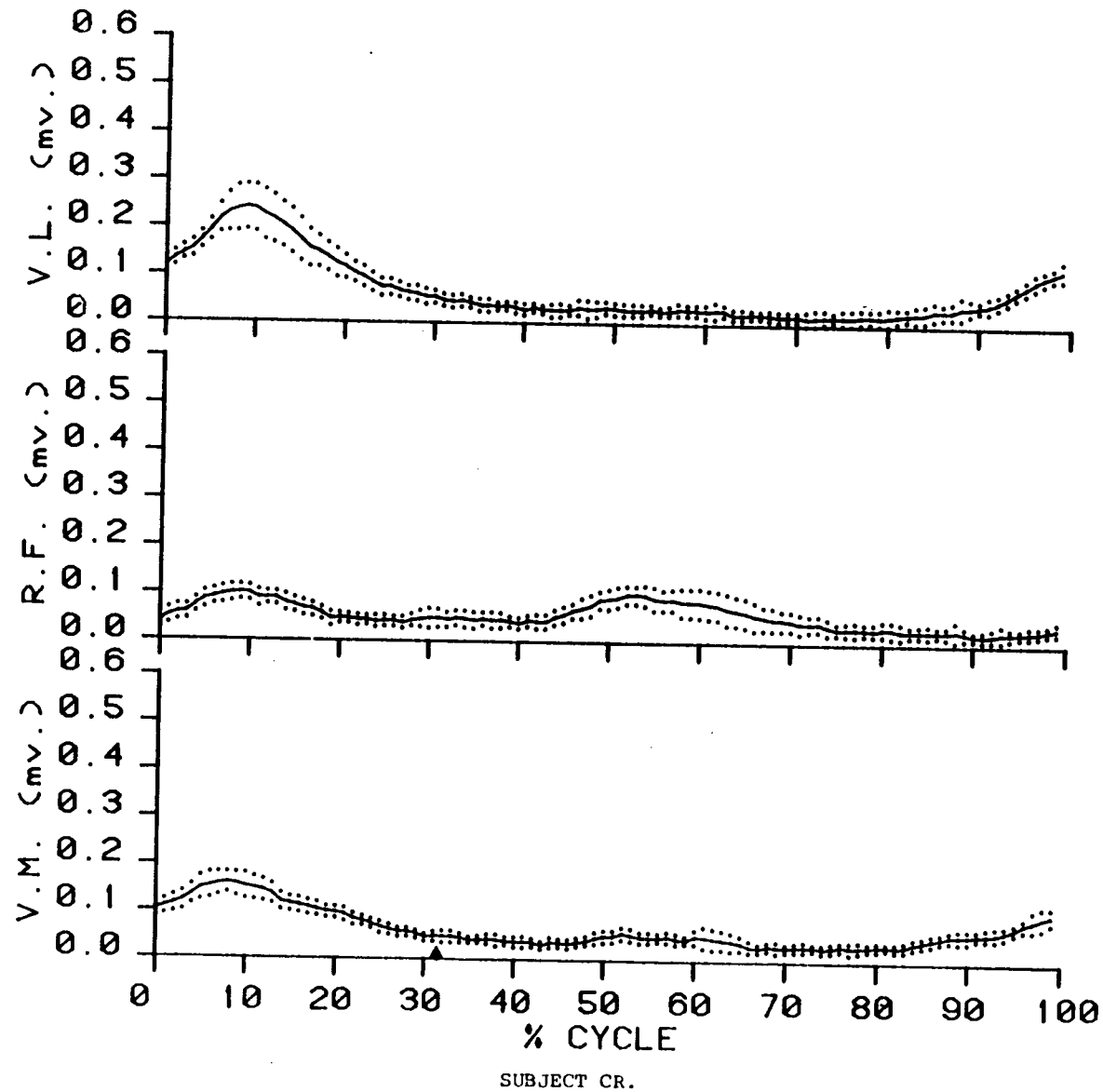
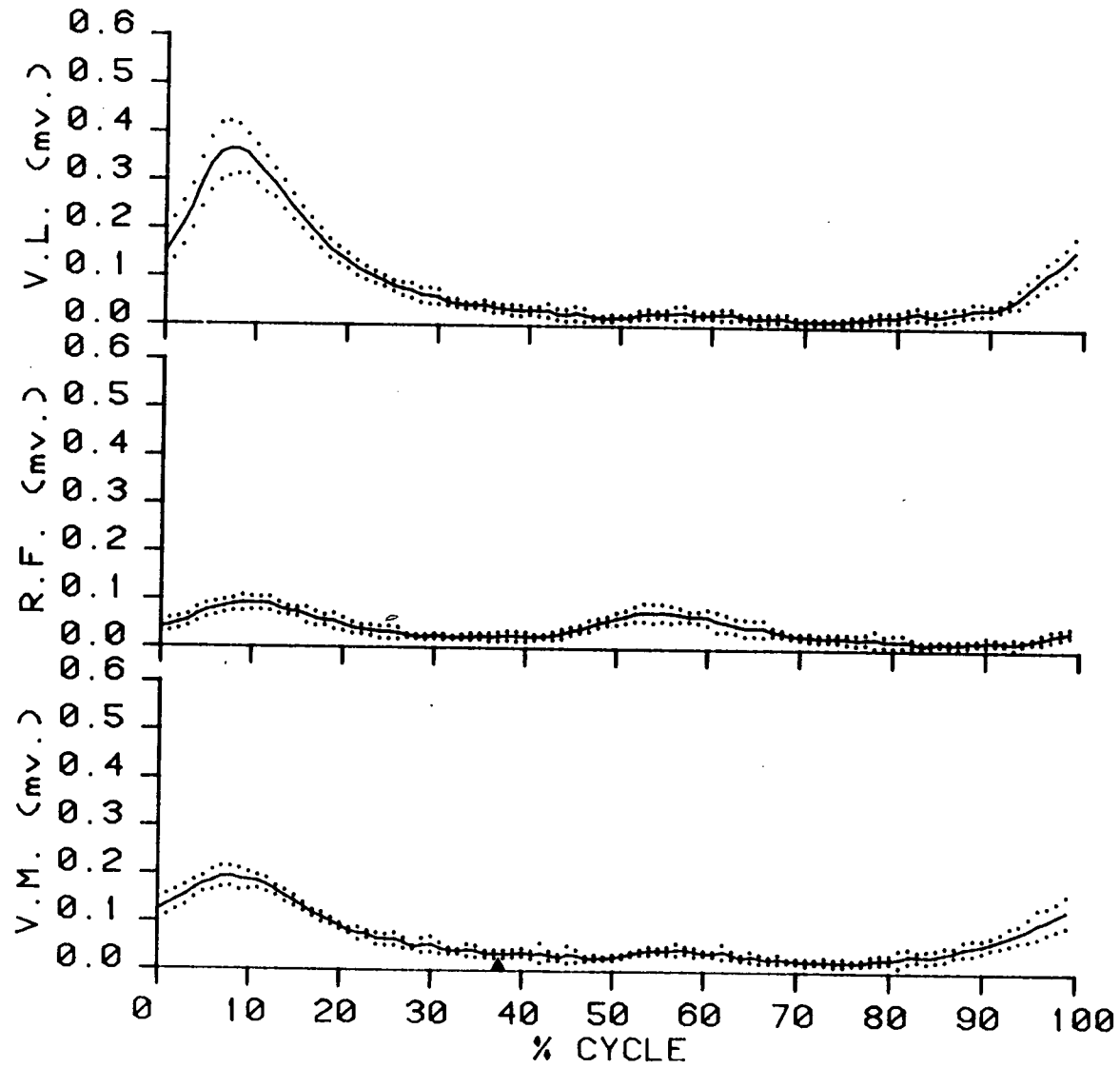
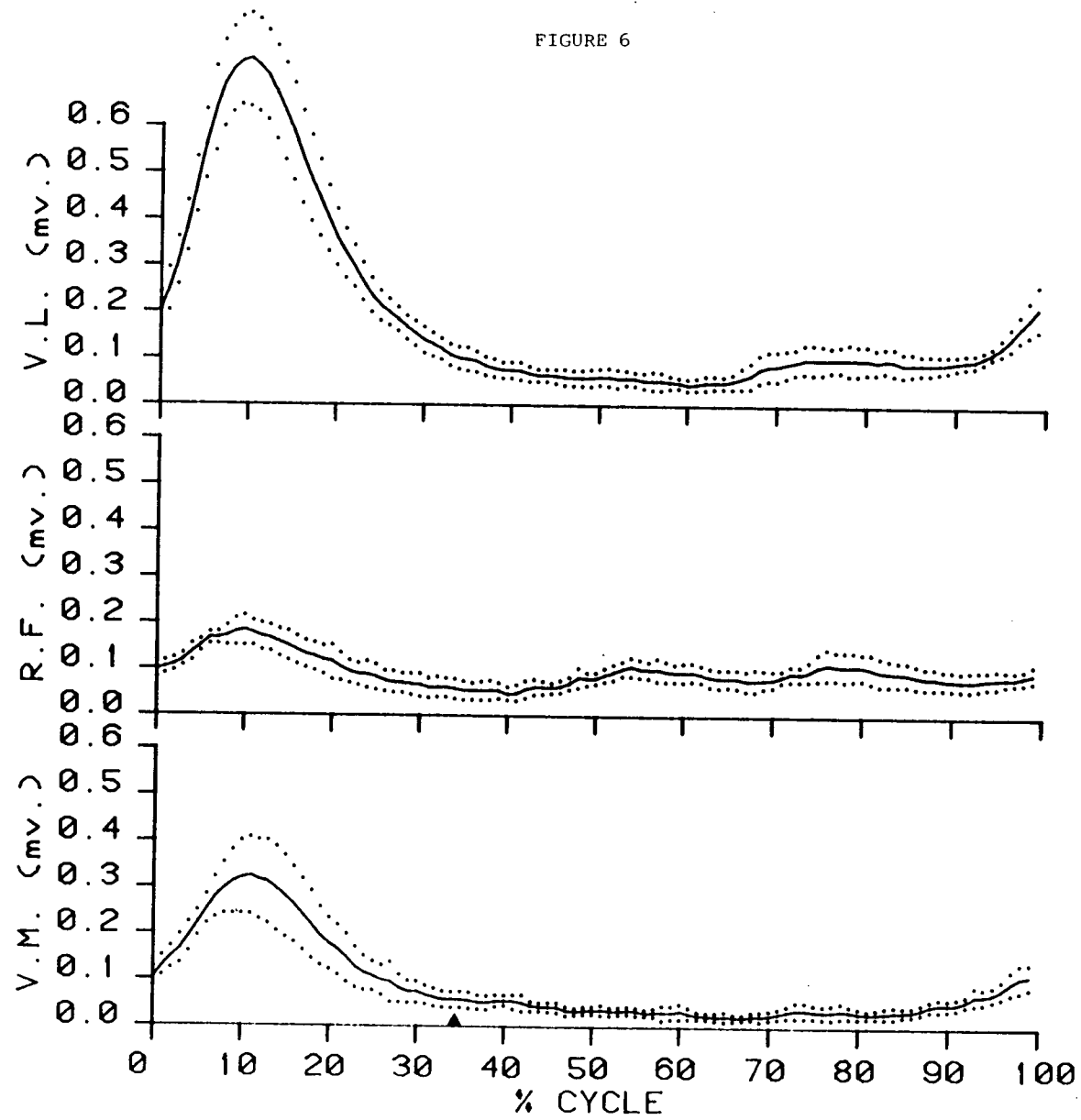


FIGURE 5



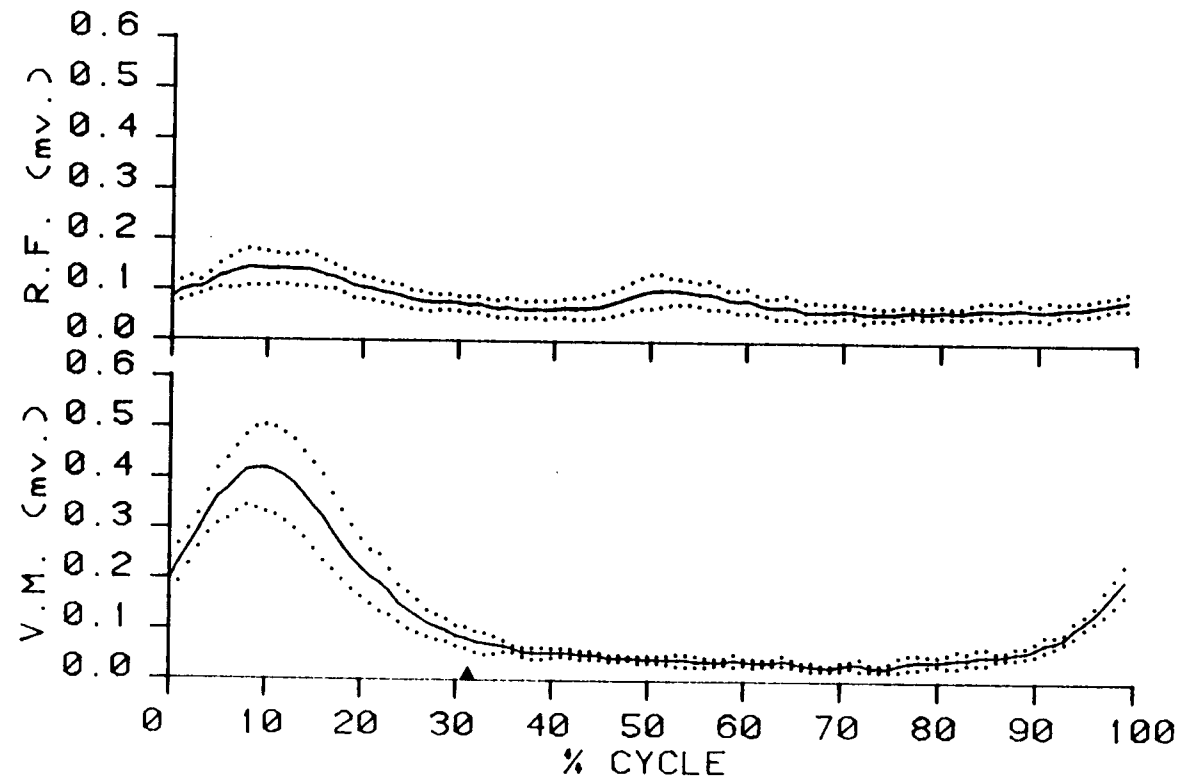
SUBJECT CS.

FIGURE 6



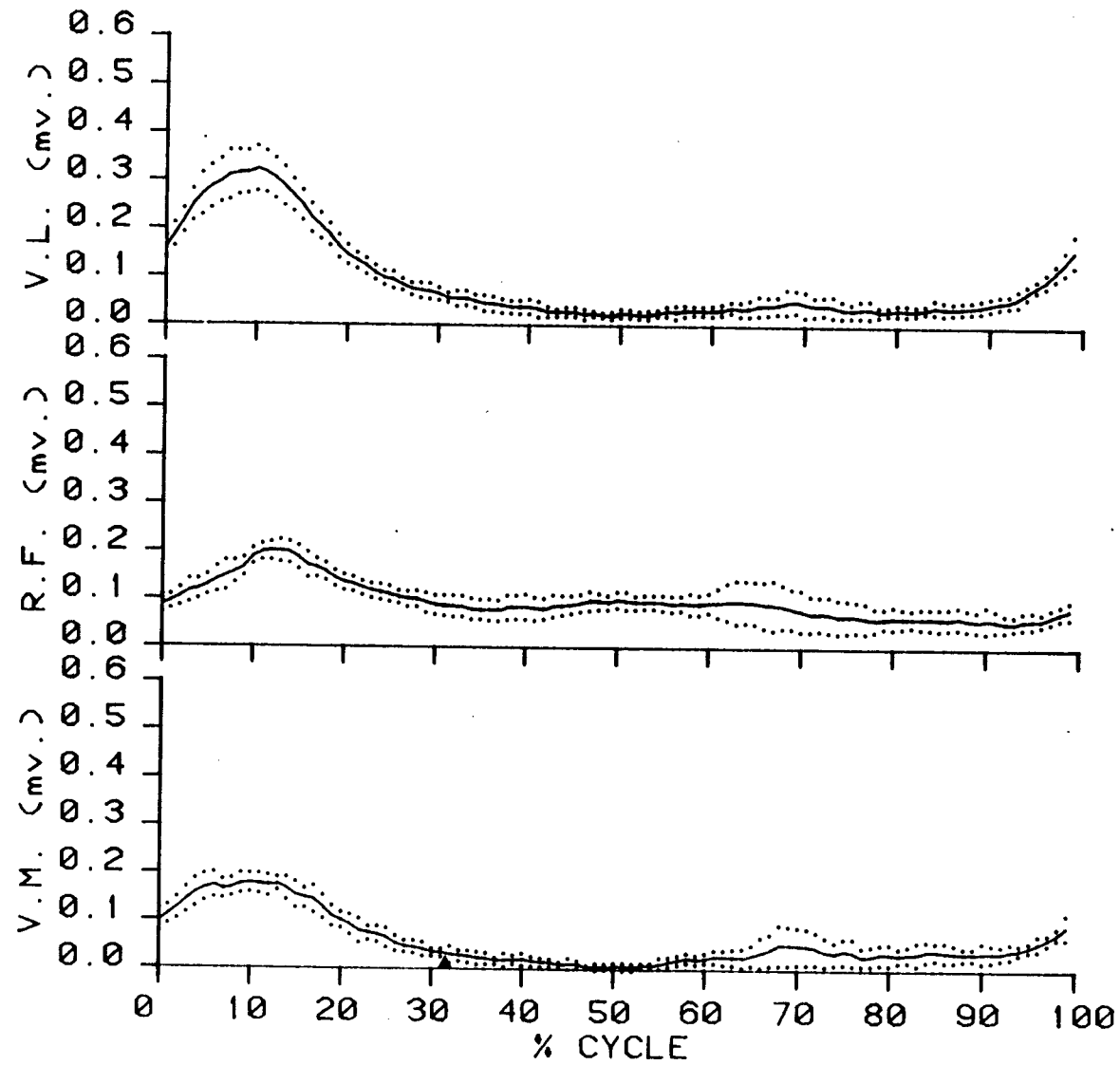
SUBJECT GG

FIGURE 7



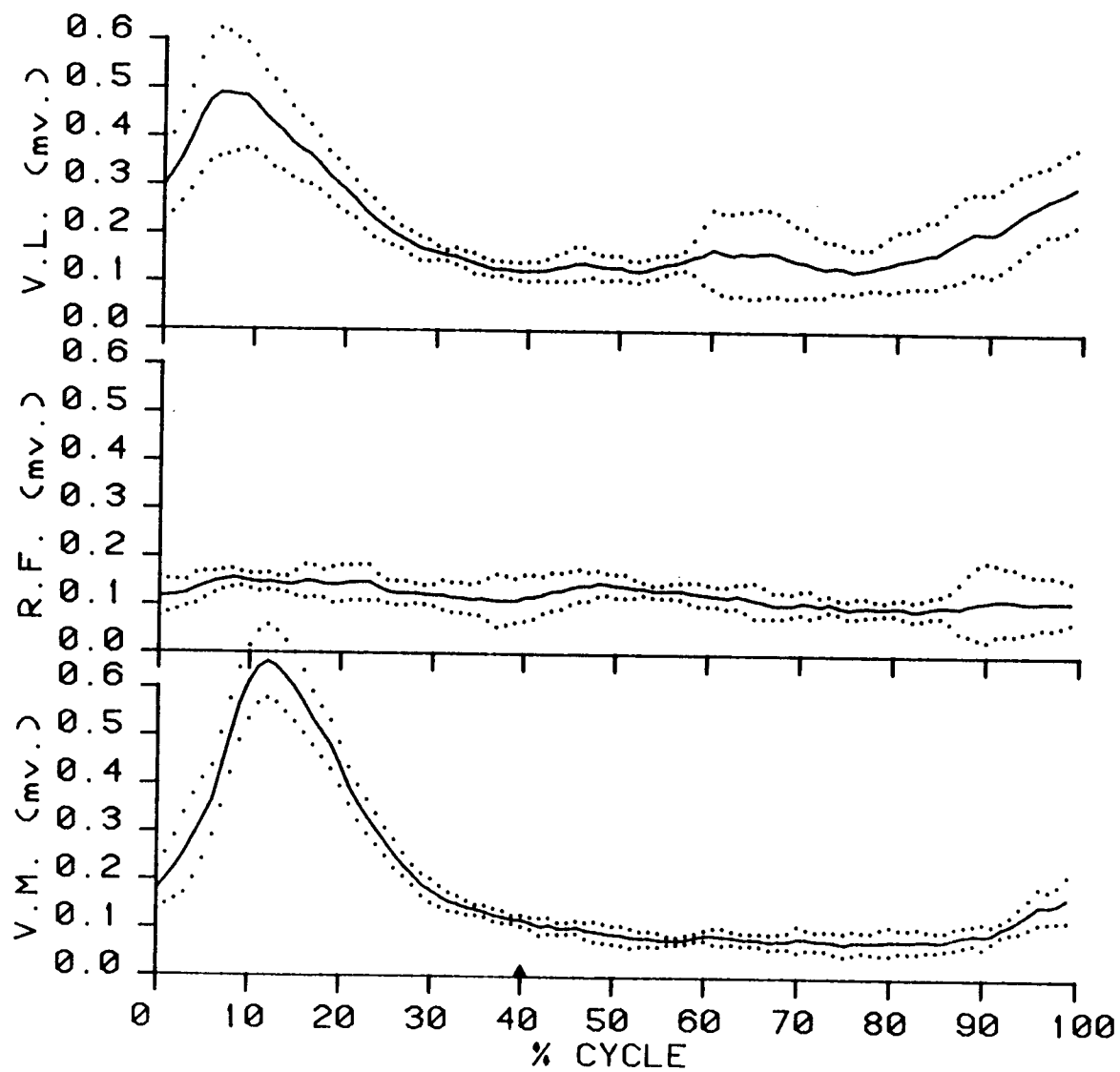
SUBJECT JF

FIGURE 8



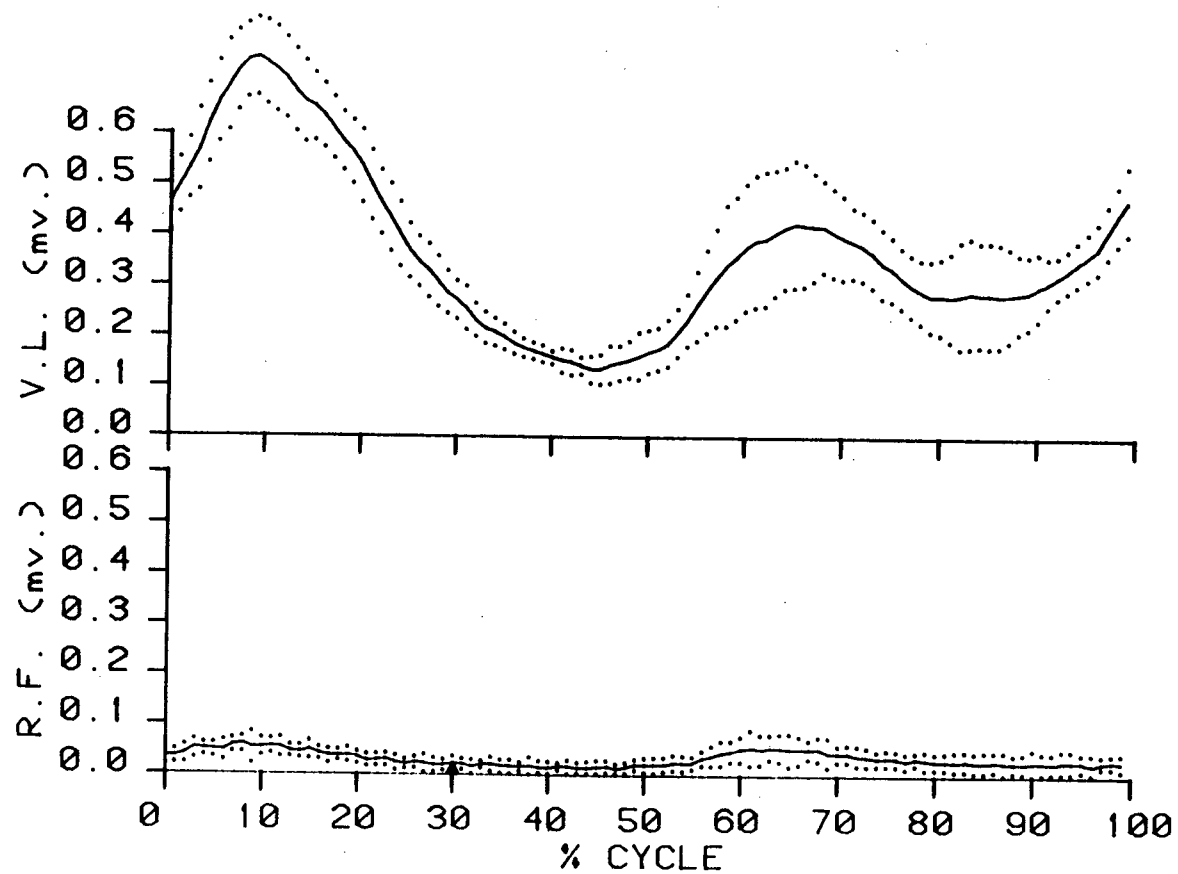
SUBJECT LS

FIGURE 9



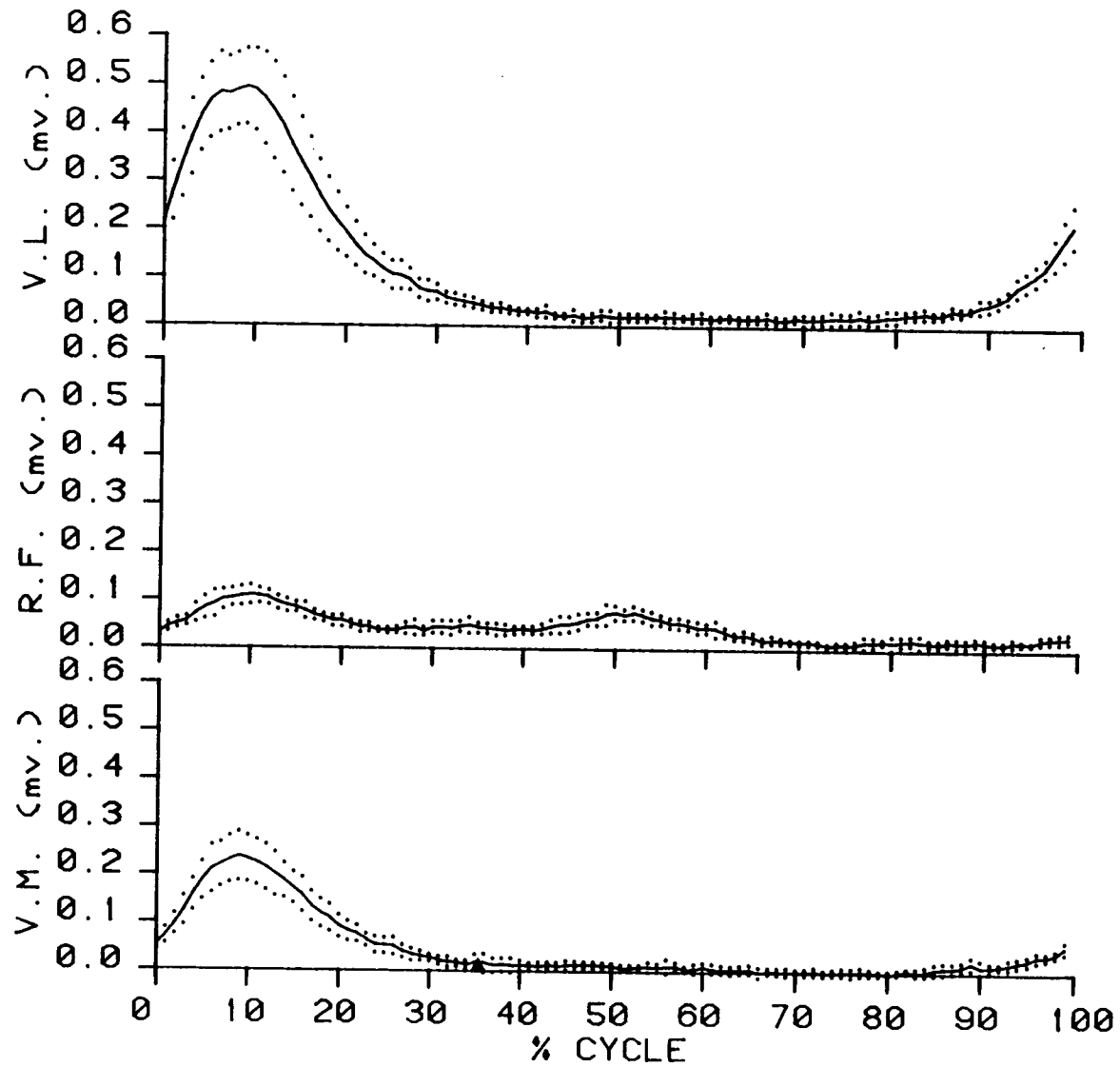
SUBJECT MR

FIGURE 10



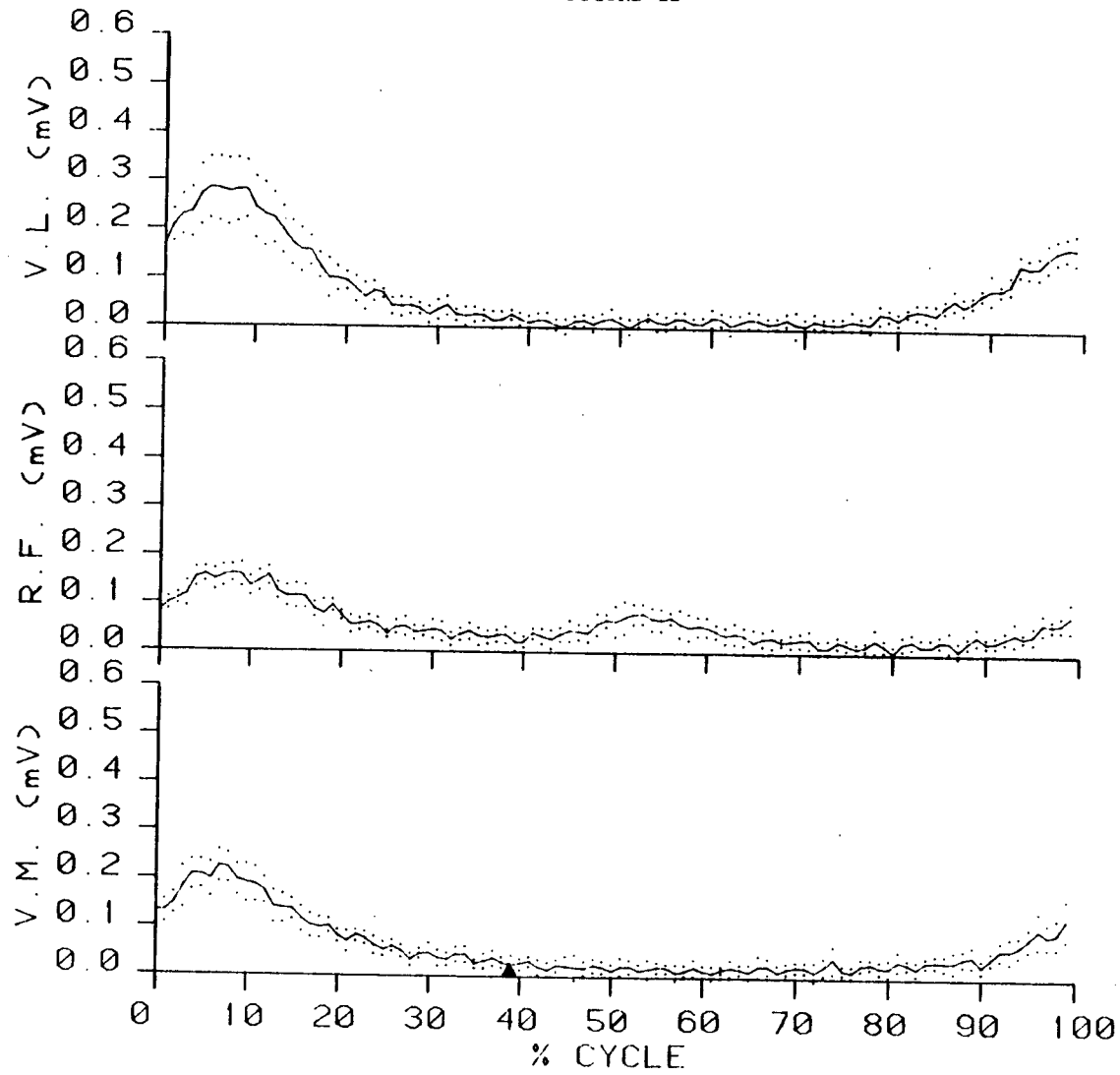
SUBJECT PB

FIGURE 11



SUBJECT PW

FIGURE 12



SUBJECT SL

FIGURE 13

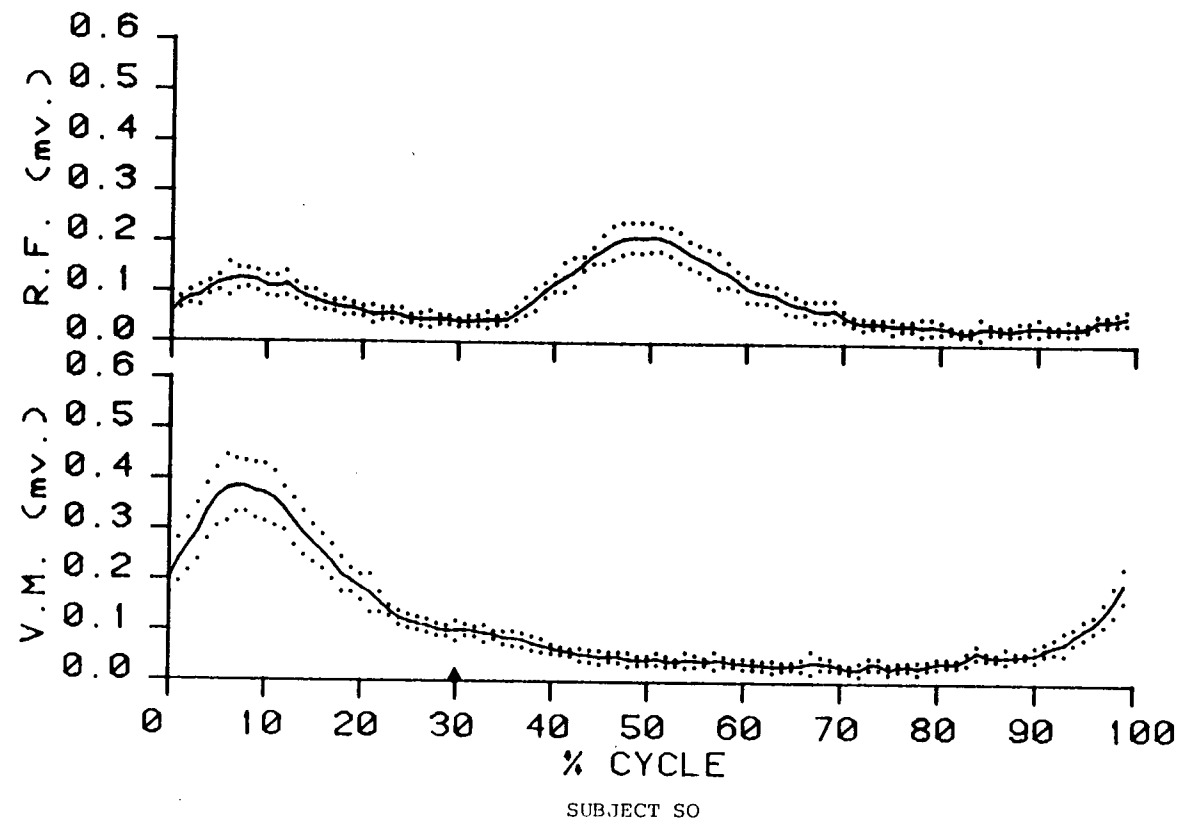


FIGURE 14

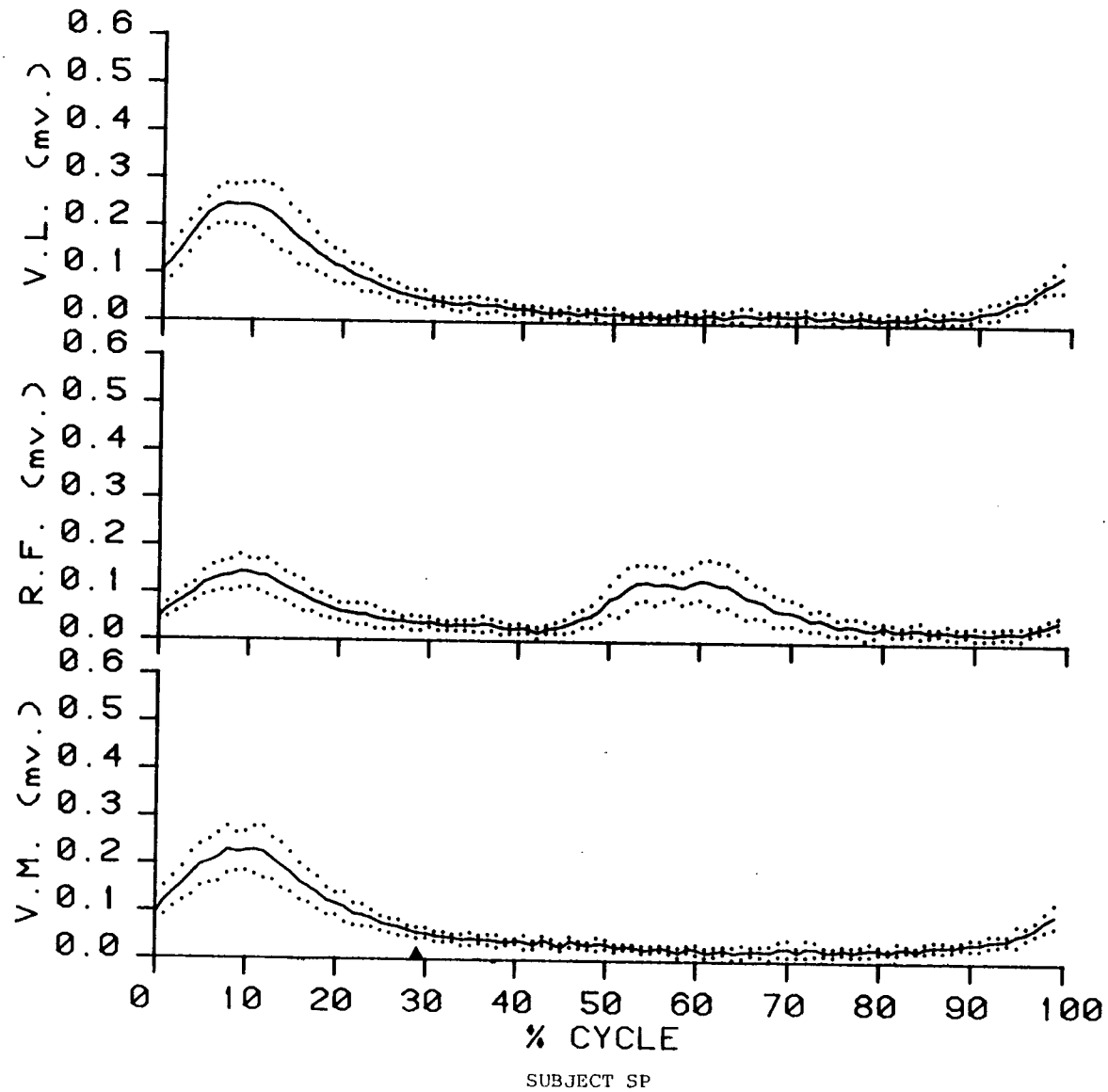
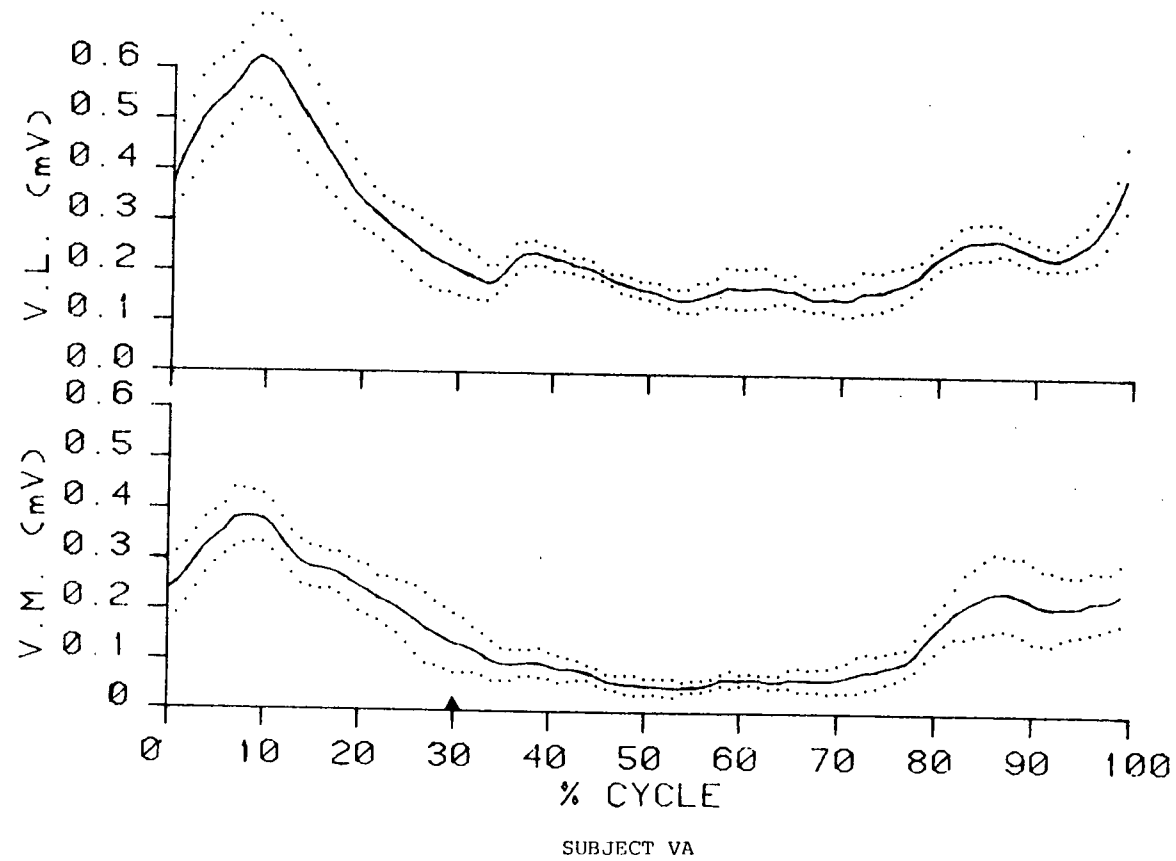


FIGURE 15



APPENDIX 2

TABLE IX

Individual Peak Torque Values for the Right Leg
at 200°/s

Quadriceps			Hamstrings	
SUBJECTS				
<u>Control Group</u>	<u>Concentric</u>	<u>Eccentric</u>	<u>Concentric</u>	<u>Eccentric</u>
CR	100	166	77	99
CS	98	197	104	132
GG	90	72	88	97
JF	137	172	139	154
LS	109	104	92	110
MR	122	198	103	125
PB	114	202	127	150
PW	90	169	74	92
SL	116	124	73	63
SO	129	193	115	135
SP	164	276	118	142
VA	82	168	72	96
<u>Experimental Group</u>				
SC	87	144	107	138
HB	128	84	111	120
EC	76	80	89	91
TR	78	110	66	66
RW	90	168	122	158
SS	114	233	96	121
JH	121	164	85	105
JG	67	132	73	92

TABLE X

Individual Concentric and Eccentric
Hamstrings/Quadriceps Ratios
For The Right Leg

SUBJECTS

<u>Control Group</u>	<u>Concentric</u>	<u>Eccentric</u>
CR	.77	.60
CS	1.06	.67
GG	.98	1.35
JF	1.01	.90
LS	.84	1.06
MR	.84	.63
PB	1.11	.74
PW	.82	.54
SL	.63	.51
SO	.89	.70
SP	.72	.51
VA	.88	.57
<u>Experimental Group</u>		
SC	1.23	.95
HB	.87	1.43
EC	1.17	1.14
TR	.85	.60
RW	1.36	.94
SS	.84	.52
JH	.70	.64
JG	1.09	.70

APPENDIX 3

Individual Muscle Activation Patterns

The clinical examination of the eight subjects with patellofemoral pain, plus the results of their dynamic strength testing is summarized in Table XI.

TABLE XI

Clinical Characteristics and Dynamic Strength
of those Subjects With Right Patellofemoral Pain Syndrome

	<u>SC</u>	<u>HB</u>	<u>EC</u>	<u>TR</u>	<u>RW</u>	<u>SS</u>	<u>JH</u>	<u>JG</u>
Age (years)	23	24	22	15	35	20	22	36
Height (cm)	165	167.5	160	155	167.5	160	167.5	152.5
Weight (kg)	56.8	63.6	53.6	54.5	59.1	61.4	61.4	50
Km/week running	24	19	40	8	19	24	24	16
Pain - location	medial	medial	infra- patellar lateral	medial	medial retro- patellar	medial retro- patellar	infra- patellar	medial retro- patellar
- duration	6-7 yrs	5 yrs	3 mo	2 yrs	2-3 yrs	6 yrs	2 yrs	6 mo
- with running	yes	yes	yes	yes	yes	yes	yes	yes
Knee alignment	valgus	valgus	valgus	recur- vatum valgus	varus	varus	varus	valgus
Q-angle	15°	20°	20°	18°	20°	17°	20°	19°
Rearfoot varus alignment	3°	8°	8°	10°	6°	10°	4°	5°
Forefoot varus alignment	10°	6°	10°	6°	4°	2°	4°	4°
Overpronation	yes	yes	yes	yes	yes	yes	yes	yes
Leg-length	equal	equal	L<R 1 cm *	equal	equal	L<R 1 cm*	equal	equal
Peak torque (N.m)								
Quadriceps								
- concentric	87	128	76	78	90	114	121	67
- eccentric	144	84	80	110	168	233	164	132
Hamstrings								
- concentric	107	111	89	66	122	96	85	73
- eccentric	138	120	91	66	158	121	105	92
Hamstrings/Quadriceps ratio								
- concentric	1.23	.87	1.17	.85	1.36	.84	.70	1.09
- eccentric	.95	1.43	1.14	.60	.94	.52	.64	.70

* left leg shorter than right by one centimeter

Certain researchers (Winter, 1984, Richards et al. 1985) believe that averaging the EMG patterns of subjects with a clinical problem masks the individual differences of each patient. It is their suggestion that in order to evaluate clinical differences between patients and a control group, it must be done on an individual basis and not by comparing the patients as a group. Winter (1984) points out, however, that in order to use this technique a large data bank of normal subjects' muscle activity is required plus improved normalization techniques to reduce the between - subject variability.

In this study the individual muscle activation patterns of those subjects with patellofemoral pain syndrome have been compared to the control group, however the results must be viewed cautiously for different reasons.

The small number of subjects in the control group (n=12) has the possibility of increasing the variability of the results. As seen in Table VII the mean EMG patterns of the subjects in the control group did not always fall within a normal (Gaussian) distribution, which makes a comparison to what is considered a 'normal' group (the control group) not as significant.

It is also important to point out that this study has only addressed and attempted to relate the alignment features, strength measurements, clinical signs and symptoms and the EMG results of each subject. Patello-femoral pain syndrome is a complicated clinical entity with considerable variation in its features from patient to patient, and there may have been certain other contributing factors that were not assessed or discussed.

These include training errors, which according to James et al. (1978) account for 60% of the lower extremity injuries to runners. Within the category of training errors there are such factors as excessive mileage, the type of running surface, a rapid change in running routine or a sudden intense workout, any one of which may provoke patellofemoral pain. Another important aspect in the occurrence of knee injuries as a result of running is footwear. A runner who has excessive pronation of the foot and who is not wearing a well supporting shoe will deform the shoe to an extent that will indicate the adverse stresses at the foot (James et al. 1978). These stresses are often reflected up to the knee.

There are other possible clinical and/or anatomical reasons for anterior knee pain, which must be differentiated from patellofemoral pain syndrome. Aside from a tight lateral retinaculum, plica, abnormal loading of the articular cartilage of the patellofemoral joint or abnormal stress to the medial soft tissues there may be true chondromalacia patellae (which would be determined by arthroscopic investigation), recurrent subluxation or dislocation of the patella and other conditions which would at first resemble PFPS until the knee has been more thoroughly examined, such as Osgood-Schlatter's syndrome, quadriceps tendinitis, infrapatellar tendon bursitis, pes anserine bursitis, generalized synovitis, fat pad syndrome (James, 1979, Ficat & Hungerford, 1977).

Therefore, in analyzing the individual results it is only possible to make inferences from the data that has been collected, and where the EMG results, the muscle strength values and the clinical features agree, keeping in mind the small number of subjects in the control group and the variability of that group.

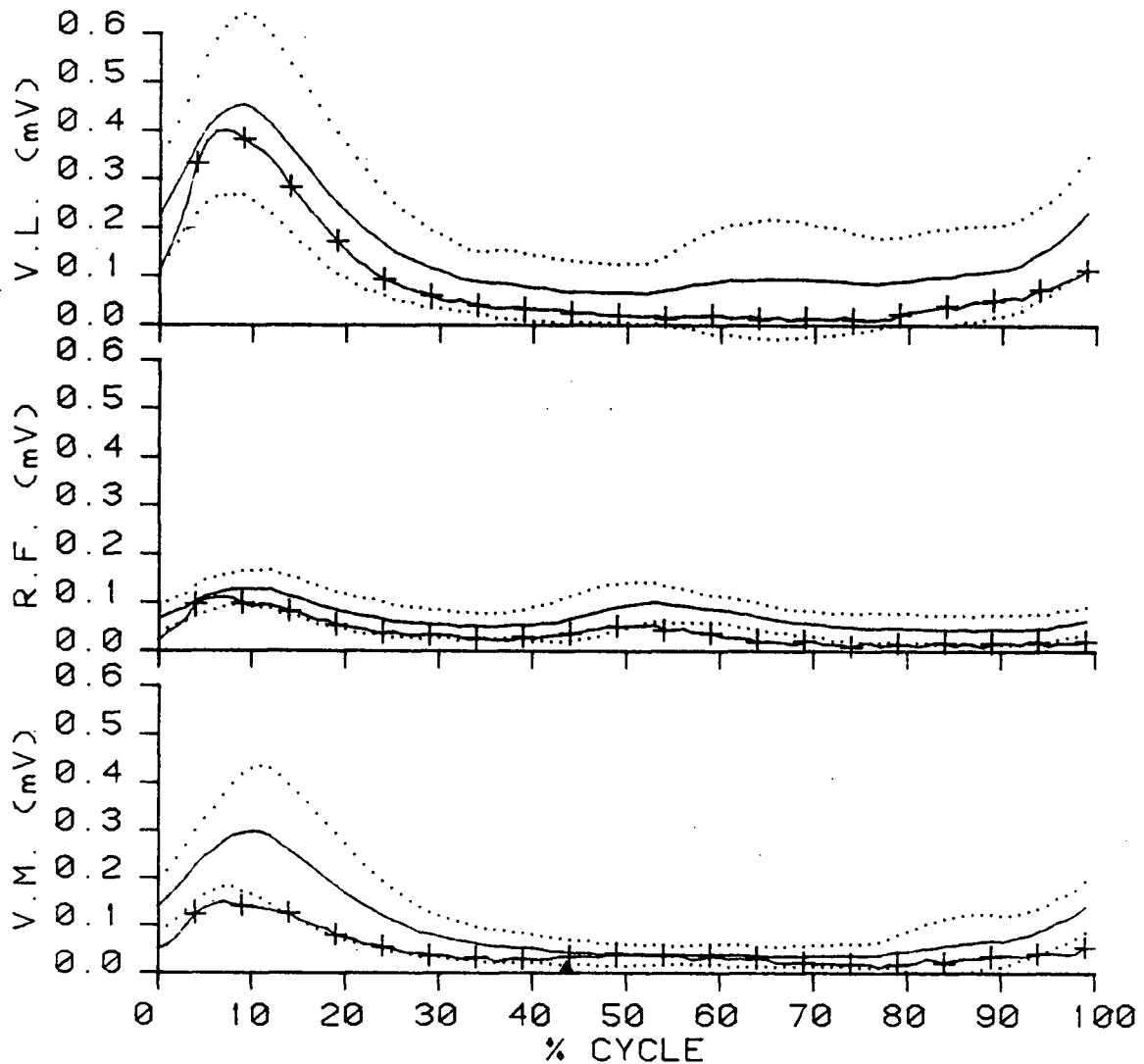


Figure 16

Subject SC. The ensemble averages (crossed line) of the vastus medialis (VM), rectus femoris (RF) and the vastus lateralis (VL) of this subject are compared to the mean muscle patterns of the control group (solid line) \pm one standard deviation (dotted line). Heel-strike is at 0 and 100% of the gait cycle, while toe-off is indicated by \blacktriangle .

As can be seen in Figure 16, the activity level of all three of the quadriceps muscles for Subject SC is less than the average EMG of the control group, and in particular the vastus medialis is outside of one standard deviation of the control group's mean during early stance. At this point in the gait cycle the knee is flexing to absorb the forces of foot contact while the quadriceps are working eccentrically to control knee flexion (Winter, 1983). There was also less EMG activity in the rectus femoris of Subject SC during swing phase, when it is thought to be working as a hip flexor (Elliott and Blanksby, 1979).

This subject's strength tests revealed that her right quadriceps were weaker than the mean of the control group both eccentrically and concentrically (Table IV, Table XI). Her hamstrings/quadriceps ratio (H/Q ratio) was 1.23 concentrically and .95 eccentrically which indicates that concentrically her hamstrings were stronger than her quadriceps and nearly the same strength eccentrically. The concentric ratio is outside of the range (.43 - .90) reported by Nosse (1982).

Comparing this subject's EMG patterns of the vastus medialis and the vastus lateralis, the results indicated a notable difference between their activity levels during stance. As the quadriceps work first eccentrically during stance and then concentrically (Winter, 1983) it may be that the lower peak EMG amplitude of the vastus medialis during the running cycle is reflected in the reduced peak torque values of the quadriceps from the strength test. In this case it may be that the vastus medialis was not able to balance the lateral pull of the vastus lateralis.

This subject had genu valgum and a Q-angle of 15° which according to LeVeau & Bernhardt (1984) enhances the tendency to lateral tracking of the patella. Her rearfoot and forefoot varus alignment would be considered moderate (Taunton, et al. 1985) and a contributing factor towards compensatory pronation of her foot (James et al. 1978). She had experienced medial knee pain for six to seven years and reported that it was present with running. Her medial knee pain may be due to earlier than normal contact of the odd facet with the medial femoral condyle as a result of lateral tracking of the patella (Kessler and Hertling, 1983), or due to the medial soft tissues being stretched and strained leading to inflammation and pain (LeVeau, & Bernhardt, 1984).

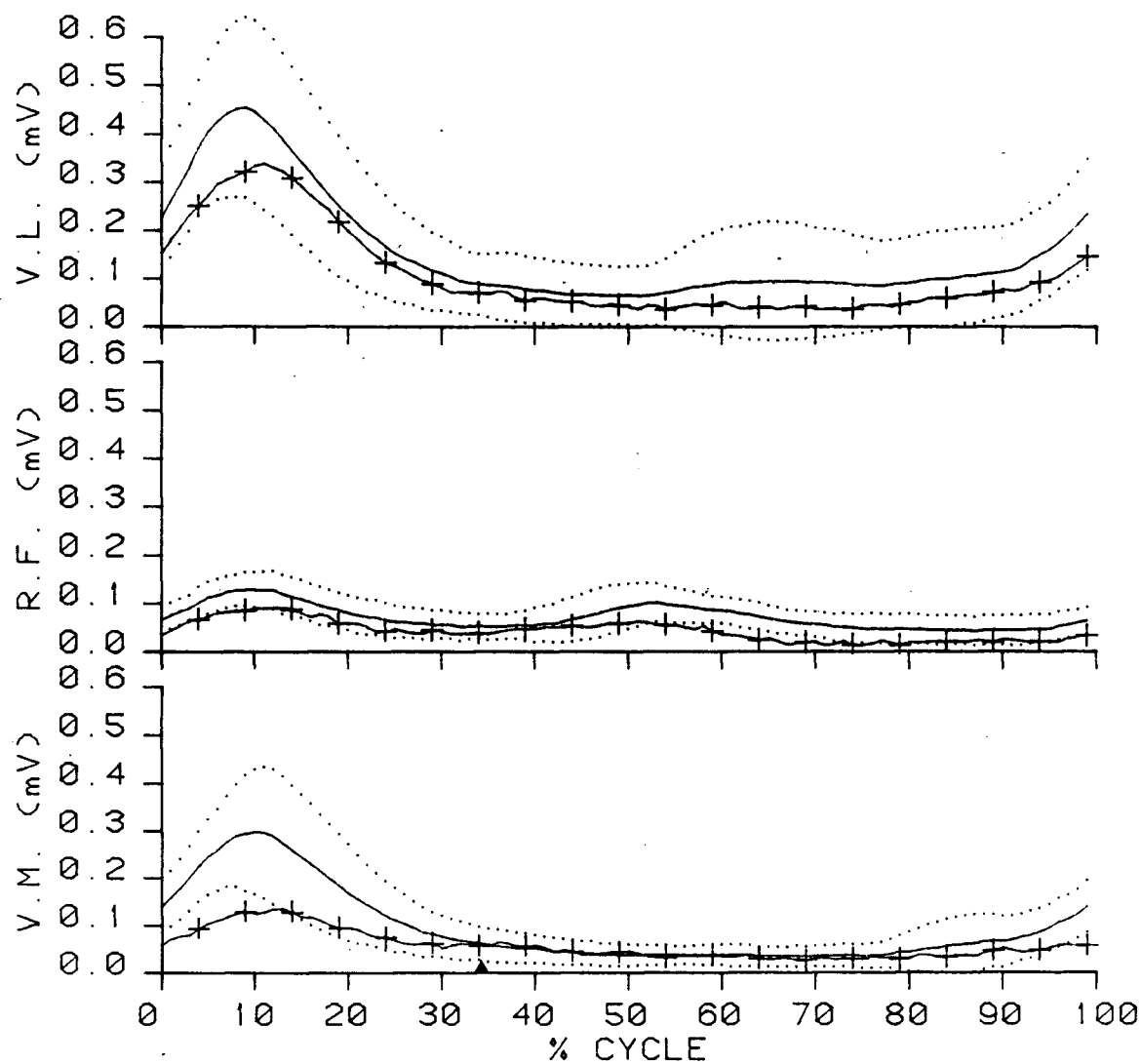


Figure 17

Subject HB. As in Figure 16, the crossed line represents the ensemble average of the vastus medialis, rectus femoris and the vastus lateralis for this subject, compared to the mean muscle activity of the control group (solid line) \pm one standard deviation (dotted line).

Figure 17 showed that the levels of muscle activity of the three quadriceps muscles from Subject HB were lower than the means of the control group. The results also revealed that although the phasing of the patterns was similar, the peak EMG amplitudes of the vastus medialis during stance and rectus femoris during swing phase were less than one standard deviation of the control group's mean.

This subject's peak torque values from the strength test were within \pm one standard deviation of the mean of the control group except for eccentric quadriceps which was less than - one standard deviation of the control group's mean (84 N.m compared to $170 \text{ N.m} \pm 50.33$). It may be that, similar to Subject SC, the reduced EMG level of the vastus medialis during stance is associated with the low eccentric peak torque value for the quadriceps from the strength test.

The H/Q ratios from this subject were concentric .86 and eccentric 1.4, which revealed that eccentrically her hamstrings were stronger than the quadriceps. Although there have been no published studies on the knee flexor/extensor strength relationship eccentrically, the mean H/Q ratio for the control group in this study was .73 ($\pm .253$).

Subject HB reported that she had experienced right medial knee pain for at least five years, which was severe enough to stop her from running. She had genu valgum, a Q-angle of 20° , moderate rearfoot and forefoot varus alignment and compensatory overpronation. Her higher than normal Q-angle and the genu valgum may have been contributing to lateral tracking of the patella and as such she could be experiencing her pain from overstretching of the medial soft tissues or from earlier than normal

contact of the odd facet on the medial femoral condyle.

Lieb and Perry (1971) and Basmajian (1970) have reported that the vastus medialis should offset the lateral and superior pull of the vastus lateralis, but it appears that in this case and in Subject SC the vastus medialis had less activity during early stance and may have allowed a greater degree of lateral pull by the vastus lateralis. LeVeau and Rogers (1980) suggest that a weakened vastus medialis is not able to contribute to the maintenance of normal alignment of the patella in the femoral groove. Therefore, a less active vastus medialis in itself may contribute to lateral tracking of the patella (Fox, 1975).

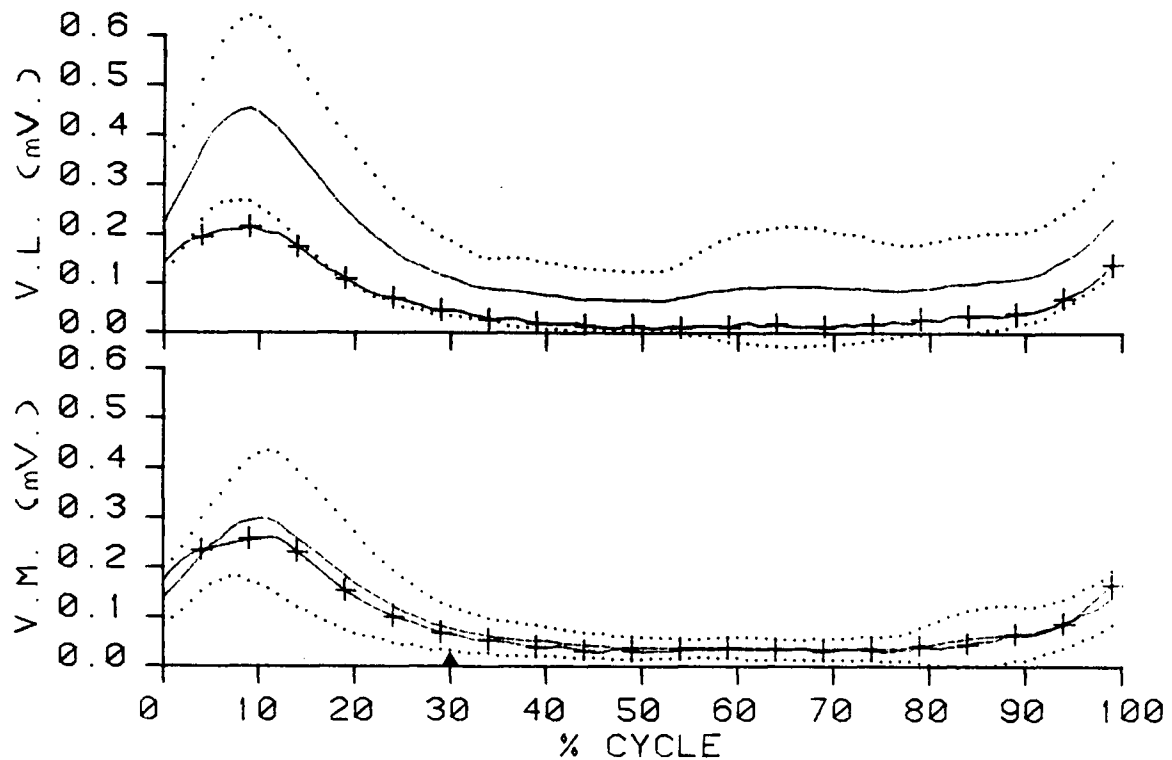


Figure 18

Subject EC. A comparison of the vastus medialis and the vastus lateralis (crossed line) to the mean muscle activity of the control group (solid line) \pm one standard deviation (dotted line).

Only the activity patterns for the vastus medialis and the vastus lateralis muscles have been presented for Subject EC, as no recording was obtained for rectus femoris. In this case, the amplitude of both muscles was below that of the control group except at heel-strike for the vastus medialis. The peak amplitude of the vastus lateralis in stance was less than - one standard deviation of the control group's mean. In fact both the vastus medialis and the vastus lateralis had nearly the same peak

amplitude during stance for this subject, although the peak amplitude of the vastus medialis was slightly greater.

All of the peak torque values from the strength test for Subject EC were lower than the control group's averages. Her H/Q ratios were 1.17 concentrically and 1.14 eccentrically indicating that the hamstrings and quadriceps were nearly the same strength although the hamstrings were slightly stronger. The literature on H/Q ratios suggests that concentrically the ratio varies from .43 - .90, depending upon the angular velocity.

Subject EC was running an average of 40 km/week. She noted knee pain three months prior to the diagnosis of PFPS. She had genu valgum with a Q-angle of 20°, her rearfoot varus alignment was 8° and forefoot varus alignment was 10°, and she had compensatory pronation. Her left leg was 1.2 cm shorter than the right.

This subject's alignment measures may have predisposed her to lateral tracking of the patella. Rather than experiencing medial knee pain however, she reported lateral and infrapatellar pain. Some of this pain could be related to higher than normal compression forces through the lateral facet due to excessive tightening of the lateral retinaculum (Ficat and Hungerford, 1977). However, the subjects were not examined particularly for excessive tightening of the lateral soft tissues, so it is not possible to completely substantiate the location of her pain.

Some authors (Mariani and Caruso, 1979; Fox, 1975) have believed that quadriceps weakness in patellar syndromes is attributable solely to weakness of the vastus medialis, however the EMG results from this subject

suggest her activity levels are nearly the same between the vastus medialis and vastus lateralis. Indeed it is the vastus lateralis that has a reduced amplitude compared to the control group and which may be related to her decreased quadriceps strength. The results of a pilot study (MacIntyre and Robertson, in press) showed that the vastus lateralis had a peak amplitude in stance higher than the vastus medialis, similar to the results of the control group in this study.

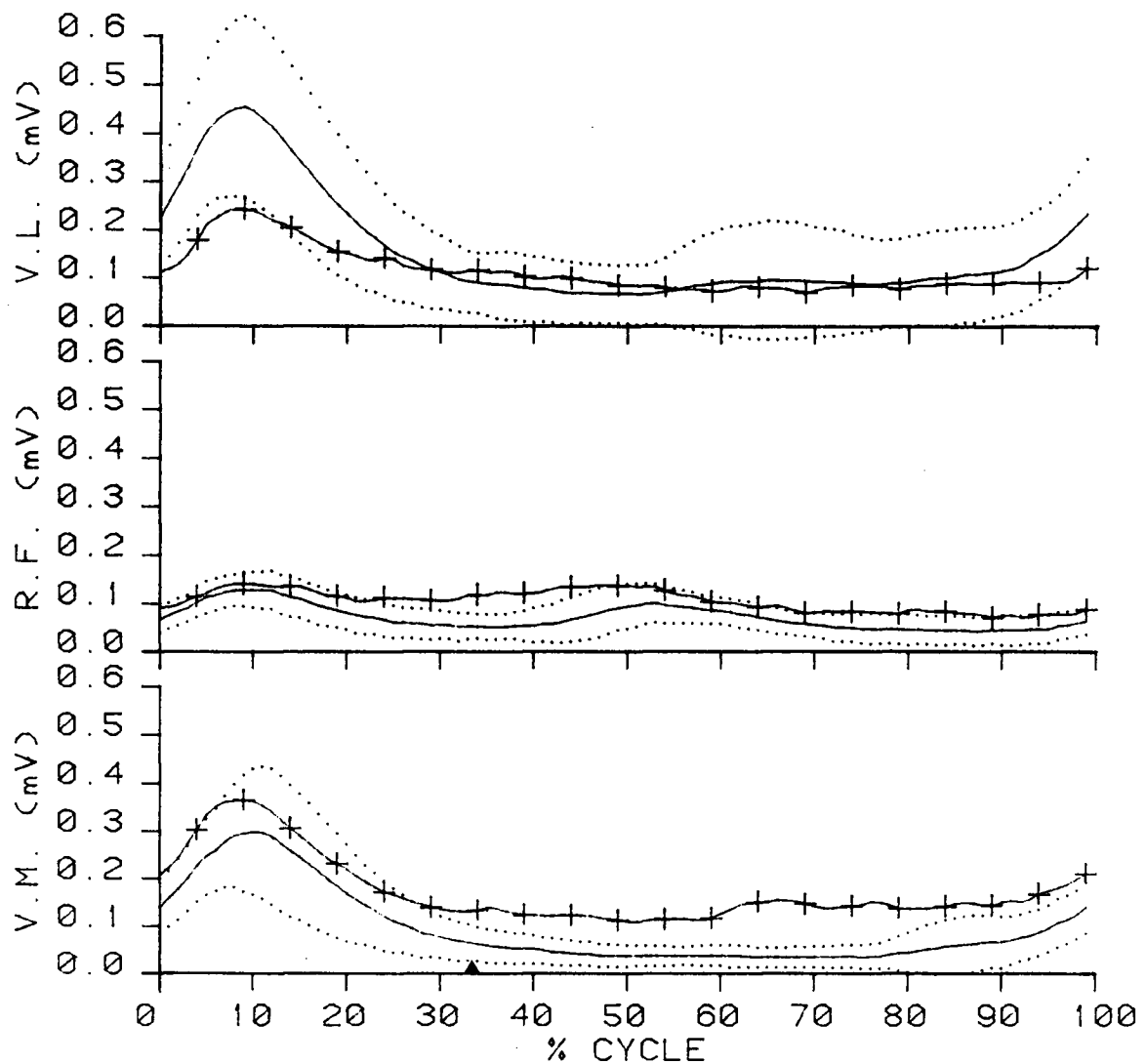


Figure 19

Subject TR. A comparison of the ensemble averages of the vastus medialis, rectus femoris and the vastus lateralis to the average muscle patterns of the control group.

The EMG records of Subject TR showed reduced activity in the vastus lateralis during the shock absorption phase of early stance. At the same time the activity in the vastus medialis was greater than the control

group's mean activity throughout the gait cycle. In fact the peak amplitude of the vastus medialis was greater than that of the vastus lateralis for this subject. Rectus femoris also had increased EMG amplitude from stance phase into early swing compared to the control group, and may indicate that it is contributing more than usual to quadriceps activity.

The peak torque values of all of Subject TR's strength tests were less than one standard deviation of the control group's mean. Her H/Q ratios were concentric .85 and eccentric .6.

This subject had complained of right medial knee pain for two years. She reported that the pain had caused her to stop running. She had genu valgum, plus recurvatum, with a Q-angle of 18° . She overpronated and had what is considered to be moderate varus alignment of her right foot. Her alignment may have been contributing to lateral tracking of the patella, however, in this case the vastus medialis was more active during stance than the vastus lateralis.

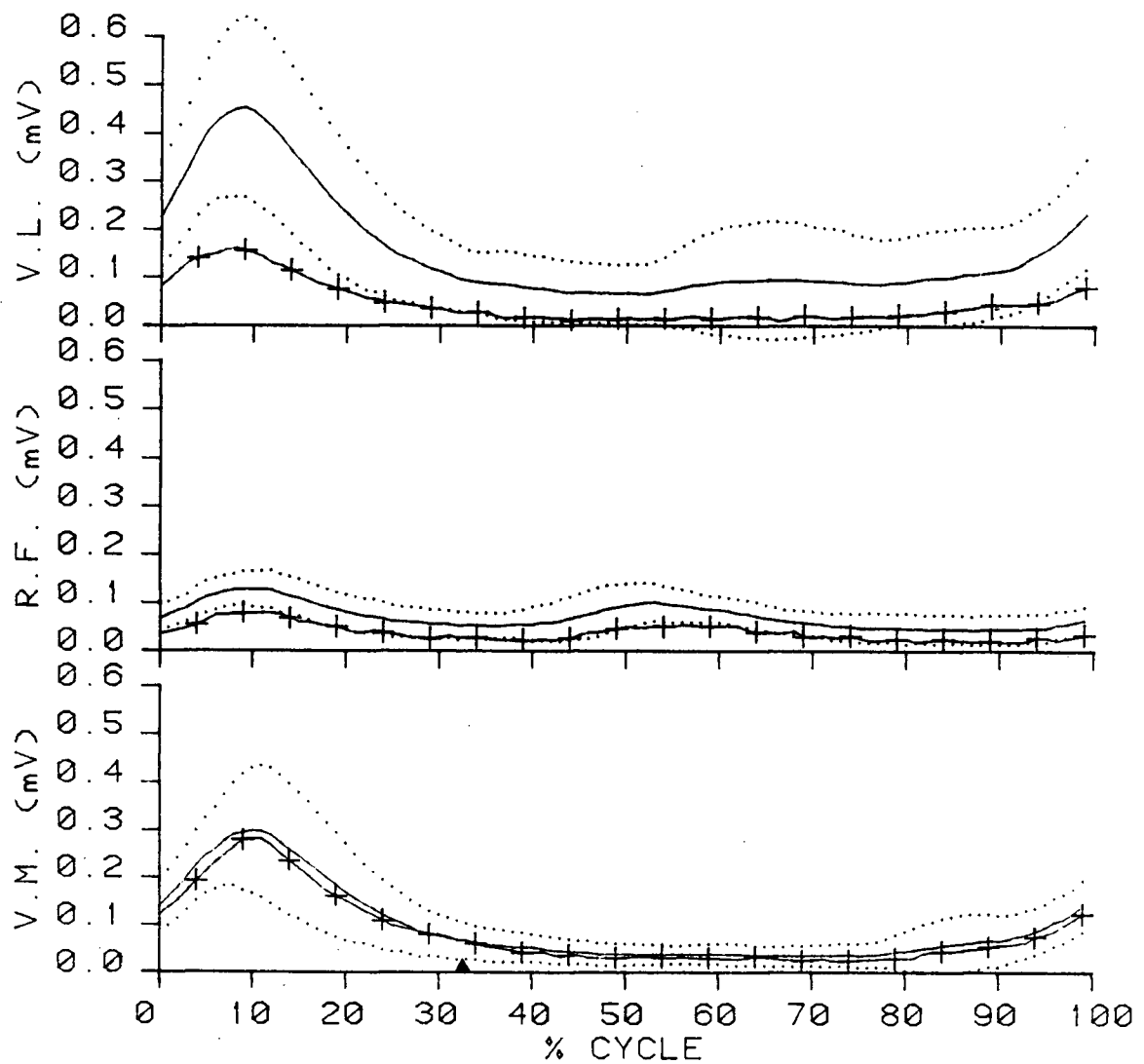


Figure 20

Subject RW Ensemble averages of the three quadriceps - the vastus medialis, rectus femoris and the vastus lateralis compared to the control group.

As can be seen in Figure 20, the EMG patterns of Subject RW followed the patterns of the control group. However, the peak amplitude of the vastus lateralis was less than one standard deviation of the control

group's mean in stance and rectus femoris was just less than - one standard deviation of the control group's mean during stance and swing.

The strength tests revealed only the concentric quadriceps torque to be weaker than the control group's mean peak torques. Her H/Q ratios were concentric 1.36 and eccentric .9 indicating that her hamstrings were stronger concentrically than her quadriceps and that there was little difference in their eccentric peak torques.

This subject had suffered from medial and retropatellar pain for two to three years. The pain was present while she was running. She had genu varum with a Q-angle of 20° and mild varus alignment of her right foot, with compensatory pronation. James (1979) has reported a sequence of malalignment features that he believes contributes to an increased Q-angle and lateral tracking of the patella. He has found that genu varum may accompany femoral neck anteversion, and that in an attempt to place the foot straight ahead rather than in-toeing, the patient externally rotates the tibia which then increases the Q-angle. Although anteversion/retroversion at the hip has not been evaluated, James' description of 'miserable malalignment' may apply to this patient.

As in Subjects EC and TR, the EMG records suggest that the vastus lateralis is not as active as the vastus medialis during stance phase, and in this case that rectus femoris is less active than the control group's mean activity.

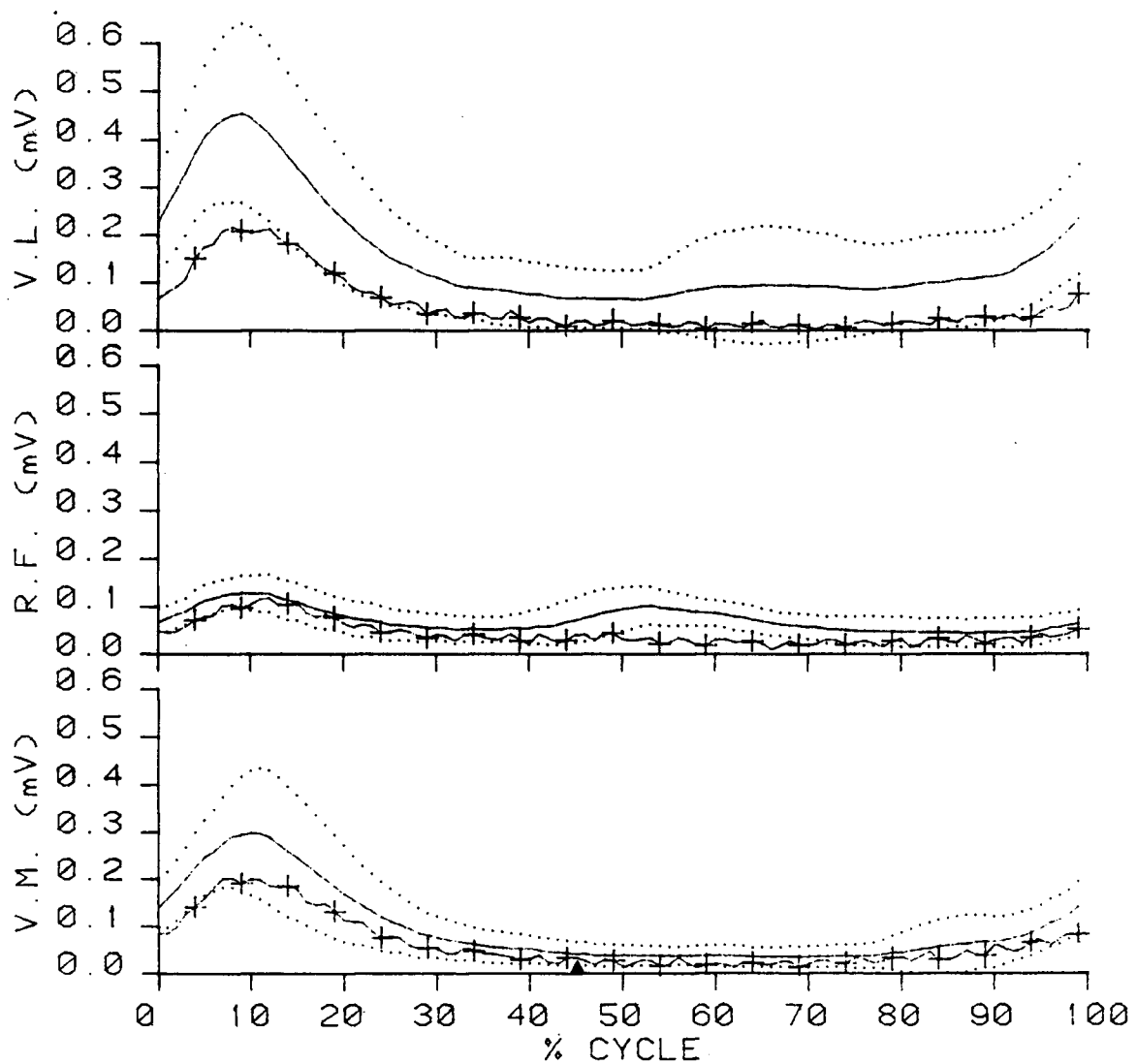


Figure 21

Subject SS. The EMG profiles of the vastus medialis, rectus femoris and the vastus lateralis superimposed on the grand ensemble averages of the control group.

The muscle activation patterns of Subject SS were all lower than the control group's average pattern. The vastus lateralis was less than - one standard deviation during stance and rectus femoris was also lower than one standard deviation of the control group's mean in swing phase.

Not only was the amplitude less, but in this case rectus femoris also deviated from its usual pattern of activity (Elliott and Blanksby, 1979; MacIntyre and Robertson, in press) because of the absence of the second curve during swing.

The strength tests for this subject were all near to the average of the control group, except for eccentric quadriceps torque which was above one standard deviation of the control group's mean. Her H/Q ratios were .84 concentrically and .52 eccentrically, indicating that her quadriceps were stronger than the hamstrings.

Subject SS reported that she had suffered from medial and retropatellar pain for six years. She had genu varum, with a Q-angle of 17° and her left leg was one centimeter shorter than the right. Her rearfoot and forefoot varus alignment was considered moderate, contributing to overpronation of her foot. Similar to Subject RW, this subject's alignment may fit James' (1979) description of 'miserable malalignment', which may have contributed to lateral tracking of the patella.

Even though this subject's strength tests were near to the control group's average or above, it would appear that the vastus lateralis was less active during the stance phase of running. Similarly, rectus femoris did not show the second burst of activity in swing phase. This subject's results indicate the value of determining an EMG percent utilization value. Richards et al. (1985) have described this value as the peak EMG amplitude during gait/peak EMG amplitude during a maximal voluntary contraction x 100%. Although this study did not lend itself to obtaining

this value due to the logistics of equipment location, it would have been a useful indicator of the percent of activation of a muscle during gait.

Four out of eight of the experimental subjects had EMG amplitudes from the vastus lateralis less than - one standard deviation of the control group's mean during the stance phase of running, while only two out of eleven of the subjects in the control group were less than - one standard deviation (Table VII). Although the present subject numbers were small this may indicate a need for further study to determine if there would be a significant difference between the groups when comparing the peak amplitudes of the vastus lateralis during stance, if subject numbers were greater. Furthermore, a statistical analysis with a t-test indicated that if the vastus lateralis had been the only muscle tested there would have been a significant difference between the groups when comparing the peak EMG amplitudes.

However, the clinical information for each of the four subjects with a reduced vastus lateralis EMG amplitude was inconsistent and difficult to explain in relation to the muscle activity. Three of the subjects had medial knee pain, while one had lateral knee pain. Two subjects had genu valgum and two had genu varum, although as LeVeau and Bernhardt (1984) and James (1979) have suggested, it is possible to have lateral tracking of the patella as a result of each type of knee alignment and the effects it has on other aspects of the lower extremity.

Additionally, the muscle strength results varied from one subject with values near to the control group's mean except for eccentric quadriceps which was above one standard deviation, to one subject who had values all

less than - one standard deviation of the control group's mean.

In discussing quadriceps weakness, the literature has emphasized that the vastus medialis is the muscle that is most often weaker (Hughston, 1968, Fox 1975, Mariani & Caruso, 1979, LeVeau & Rogers, 1980) but it would appear from the results of this study that weakness of the vastus lateralis may also occur in PFPS and further investigation would be warranted.

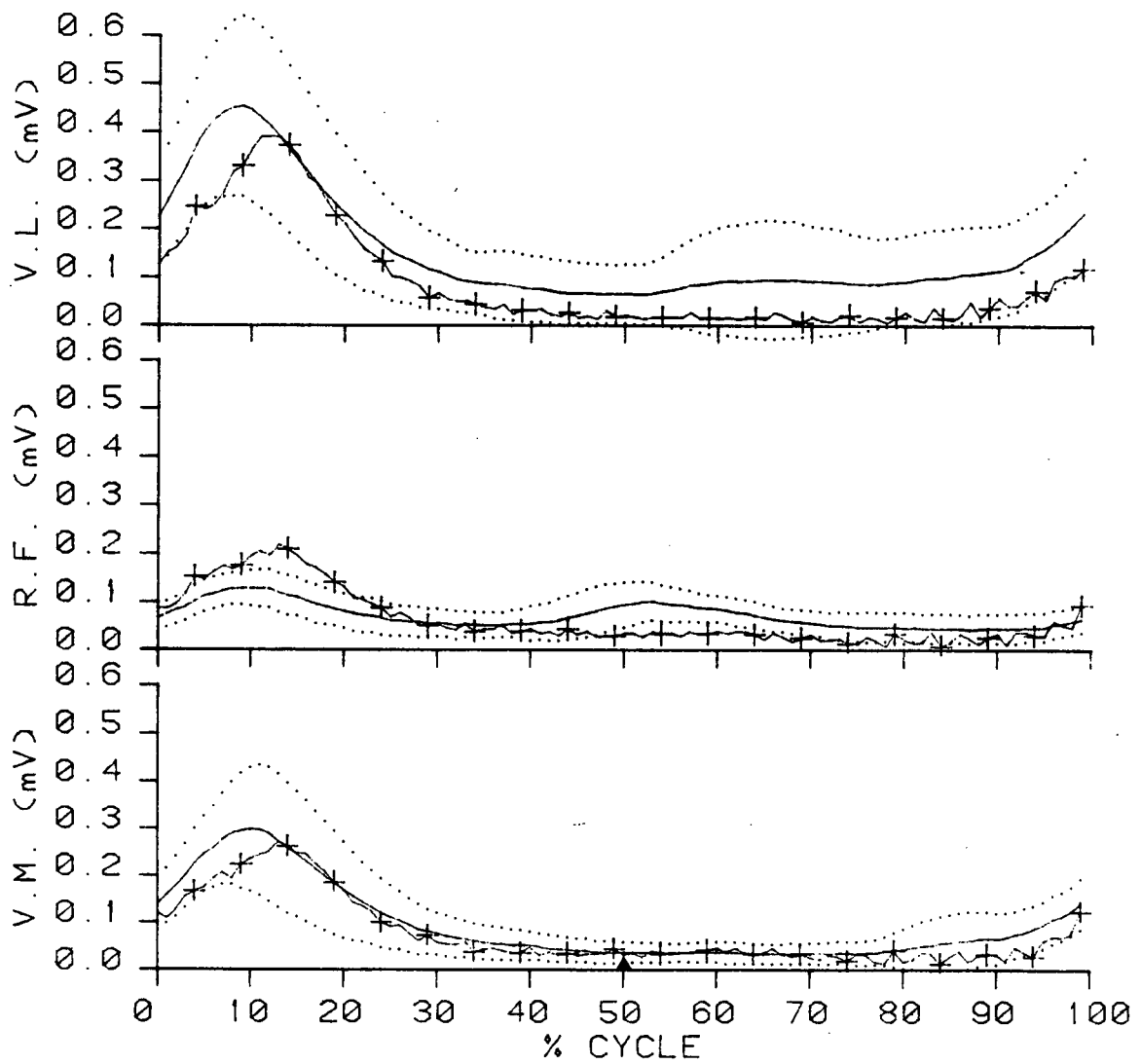


Figure 22

Subject JH. A comparison of this subject's ensemble averages of the vastus medialis, rectus femoris and the vastus lateralis to the average patterns of the control group.

The EMG profiles for the vastus lateralis and the vastus medialis from this subject had a similar pattern to the control group's average pattern, although the peak amplitudes were slightly later and lower during stance

than the control group. The peak amplitude for rectus femoris during stance was above one standard deviation of the control group's mean, but during swing phase there was an absence of the second curve.

This subject's strength values were all near to the control group's averages and her H/Q ratios were concentric .7 and eccentric .64.

She reported infrapatellar pain of two years duration and although she experienced the pain while running, she had not stopped. Her Q-angle was 20°, she had genu varum, mild varus alignment at her foot and compensatory pronation.

From the EMG records, there appeared to be less recruitment of rectus femoris during swing phase for this subject, but a greater level of activity during stance phase. Otherwise her muscle strength and EMG activity levels were near to the control group's mean.

Five out of seven of the experimental subjects had an EMG amplitude less than - one standard deviation of the control group's mean during the swing phase of rectus femoris, while two out of eleven of the control group's subjects fell outside of - one standard deviation (Table VII). Although this study has not considered the role of rectus femoris as a hip flexor during the swing phase of running it would appear that this would be a worthwhile project to pursue.

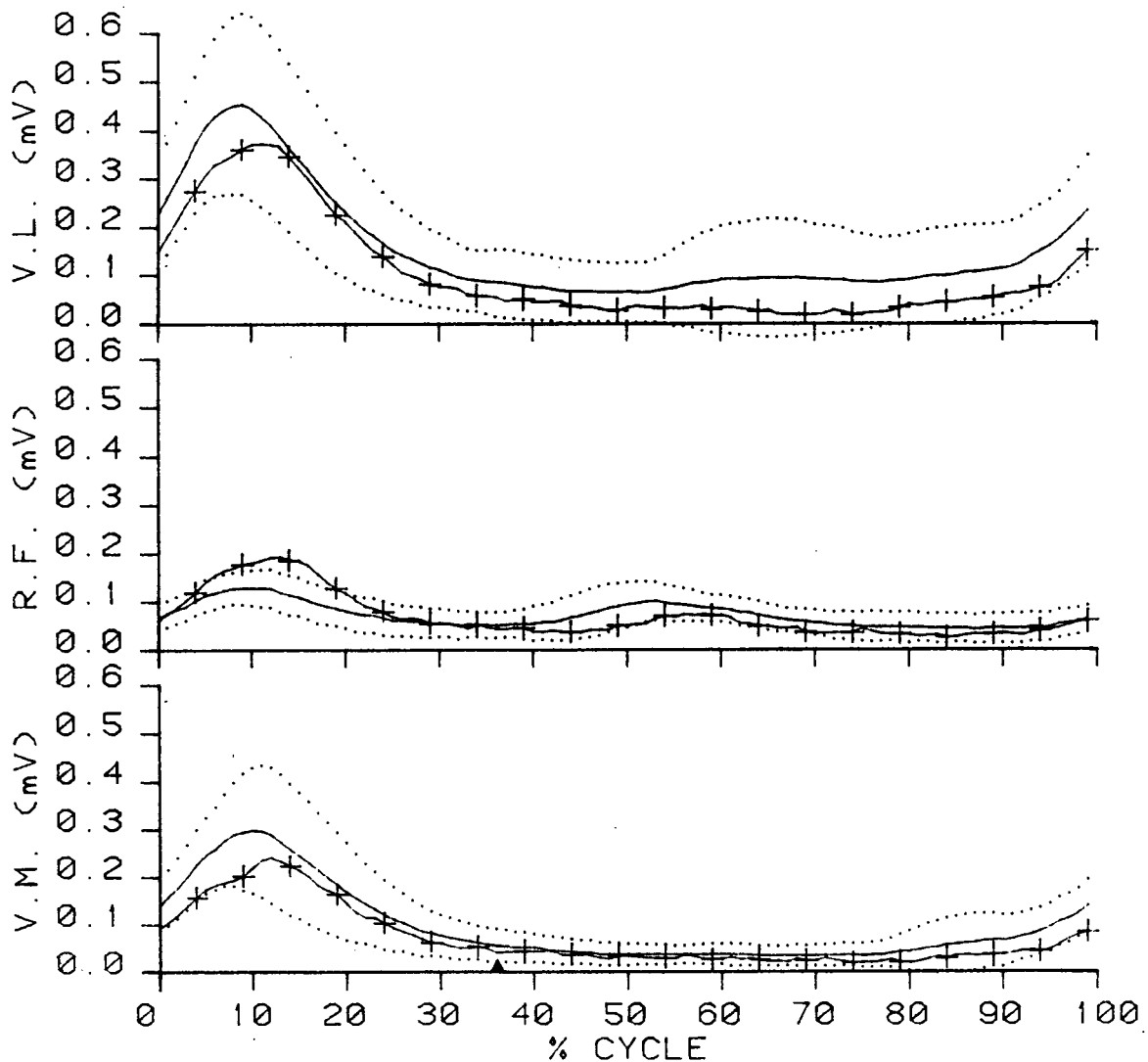


Figure 23

Subject JG. The ensemble averages of the vastus medialis, rectus femoris and the vastus lateralis compared to the control group's average muscle activity.

This subject's EMG patterns followed the profiles of the control group but were slightly lower in amplitude, except for rectus femoris during stance. In this case the peak amplitude of rectus femoris was above one standard deviation of the control group's mean.

Her muscle strength values were all less than the control group's means and in fact, the concentric quadriceps and hamstrings were outside of - one standard deviation. Her H/Q ratios were concentric 1.09 and eccentric .70 which indicated that her concentric quadriceps and hamstrings were nearly the same strength, while during eccentric testing her quadriceps were stronger than the hamstrings.

She had noted medial and retropatellar pain for six months. Her Q-angle was 19° , with genu valgum, mild varus alignment of her foot and compensatory pronation.

As in Subject SS the apparent incongruency between this subject's decreased strength values but EMG patterns similar to the control group's average patterns may have been explained by a percent EMG utilization value. It may be that although her muscles are weaker she was recruiting at a high percentage during running.

Conclusion

Although the results of the group EMG patterns indicated that there was no statistically significant difference between the two groups, analyzing individual EMG patterns could prove to be valuable in directing a rehabilitation program for the runner. If there was a large bank of normal data with which to compare, the muscle activity of a patient with PFPS or any other clinical condition could be analyzed during functional activity and those EMG patterns that deviated from the normal distribution could be the focus of a muscle re-education program in regard to strengthening, electrical stimulation and gait training.

The results of this study suggest that there may not be a particular pattern of muscle activity that is common to all patients with PFPS. This lack of a common finding may be due to the many possible interactions of malalignment features and etiology that the clinician may find in each individual. However, the findings must be considered cautiously due to the small number of subjects in this study.

This study has attempted to compare clinical features and EMG activity during running but it is necessary to recognize that there are some limitations in this analysis. As the knee is flexing during early stance and absorbing the forces of the foot hitting the ground, not only is there eccentric activity of the quadriceps to control knee flexion (Winter, 1983), but according to Elliott and Blanksby (1979) there is a simultaneous contraction of the hamstrings group. During swing phase there is also knee flexor activity. Considering that five out of eight of the experimental subjects had H/Q ratios greater than one, indicating that

the hamstrings were stronger than the quadriceps, it would have been of benefit to study the activity of both the quadriceps and the hamstrings electromyographically during running.

Additionally, a comparison of the muscle activity patterns of the experimental group revealed that there was more or less activity than the control group's mean EMG profile, but this did not indicate what degree or percent of muscle activity was involved for each subject. As suggested in the discussion, a percent EMG utilization value, which Richards et al. (1985) have described and used may have allowed an explanation as to why some subjects had normal muscle strength during testing but decreased muscle activity functionally and conversely, decreased muscle strength but EMG activity during running which closely approximated that of the control group. It would also add information in relating the individual EMG profiles to the control group's mean EMG pattern.

Although we recognize these limitations, each attempt to relate clinical features with functional muscle activity makes a contribution to the understanding of this relationship and provides a basis for the next study.

APPENDIX 4

REVIEW OF THE LITERATURE

OVERVIEW OF THE CHAPTER

The first part of this chapter entails a review of the literature on patellofemoral pain syndrome. The anatomy and biomechanics of the patellofemoral joint are addressed before the discussion regarding the clinical features and the more complex issue of the etiology of patellofemoral pain.

The second and third major parts of the literature review concern the analysis of muscle activity at the knee during running. A discussion of electromyography, in particular reports of studies on the knee muscles during running, leads into a review of other types of kinematic analyses of running. Finally, a review of the literature concerning the relatively new concept of isokinetic muscle activity and strength testing is presented.

PATELLOFEMORAL PAIN SYNDROME

Introduction

According to Malek and Mangine (1981), the first description of degenerative changes of the patellofemoral joint was reported in the early 1900's. Since then, they report that as many as 400 articles have been written attempting to explain the patellar syndromes.

These same authors suggest that patellofemoral pain syndrome (PFPS) is the major cause of knee pain in most sports medicine clinics in the U.S. Clement et al. (1981), in a two year retrospective survey conducted in Canada, found that amongst their patients the knee was the most commonly injured site and PFPS the most common injury.

Anatomy of the Patellofemoral Joint

The patella, which is the largest sesamoid bone in the body, is interposed in the quadriceps tendon (Malek and Mangine, 1981). During flexion and extension of the knee the patella should glide in line with the long axis of the femur. In order to do this, stabilization of the patella is provided by active and passive elements of the extensor mechanism plus torsional and angular alignment of the femur and tibia (James, 1979).

The passive stabilizers include the joint capsule which encloses both the tibiofemoral joint and the patellofemoral joint, the medial and lateral retinacular expansions, the medial and lateral patellofemoral ligaments, and the patellar tendon (Ficat and Hungerford, 1977). The lateral patellofemoral ligament is a part of the lateral retinaculum. The

deep layers of the lateral retinaculum expand into the retinaculum of the vastus lateralis muscle and the iliotibial tract. Ficat and Hungerford (1977) suggest that the lateral retinaculum is normally thicker than the medial retinaculum, and because it is also reinforced by the iliotibial band and vastus lateralis, it may accentuate the tendency to lateral displacement of the patella.

The patellar tendon, which stabilizes the patella inferiorly, limits the proximal ascent of the patella from the tibia and establishes the position of the patella relative to the femoral condyles. It is normally aligned along the long axis of the tibia but when its direction of pull is slightly lateral from proximal to distal, it adds to the tendency to lateral displacement of the patella (Ficat and Hungerford, 1977).

The bony contours of the femoral sulcus and the configuration of the patella are also considered passive or static stabilizers. The triangular shaped patella lies anterior to the tibiofemoral joint and is attached proximally to the quadriceps by the quadriceps tendon, and distally to the tibial tubercle by the patellar tendon. The posterior surface is covered by articular cartilage over 75% of its surface and is divided into five regions - the superior, inferior, medial, lateral and odd facets. A central vertical ridge separates the medial and lateral regions (James, 1979).

The intercondylar groove on the anterior aspect of the distal femur represents the femoral articular surface. The central groove corresponds to the vertical ridge on the patella and divides the femoral surfaces into medial and lateral. Hyaline cartilage covers the articular surface.

Normal depth of the intercondylar groove and height of the lateral femoral condyle buttress the patella against lateral dislocation (James, 1979). The depth of this femoral articulation is also important in the congruency of the patellofemoral joint, as is the shape of the patella. Wiberg (1941) has described six configurations of patellae, each one contributing differently to the congruency of the joint.

The patellofemoral joint is supplied by the popliteal artery which gives branches medially and laterally that form a collateral circulation at the knee (Anderson, 1983). Innervation to the knee is from the third lumbar to the second sacral segments. The antero-medial and medial aspects are supplied by the third lumbar segment, which also supplies the hip. Therefore, when assessing knee pain one must remember that the lumbosacral region or the hip may refer pain to the knee (Kessler & Hertling, 1983).

All four of the quadriceps muscles are considered to be active stabilizers, with the vastus medialis reinforcing the medial retinaculum and medial patellofemoral ligament, and the vastus lateralis reinforcing the lateral soft tissues. However, the more distal segment of the vastus medialis, called vastus medialis oblique (VMO), is thought to be the most important dynamic stabilizer of the patella (Malek and Mangine, 1981). It has been reported by Lieb and Perry (1971) that the major function of VMO in patellar alignment is to offset the superior and lateral pull of vastus lateralis. Basmajian (1970) and James (1979) have suggested that VMO prevents lateral displacement of the patella due to the orientation of its fibres into the patella at an angle of approximately 50° to the long axis of the femur.

Although it appears to be a significant muscle in patellar alignment and in the final degrees of knee extension, it is important to note that VMO can not work alone to extend the knee (Lieb and Perry, 1971). In fact, all of the quadriceps work together throughout the full range of knee extension (Hallen and Lindahl, 1967).

The pes anserine muscles (sartorius, gracilis and semitendinosus) insert medially on the proximal tibia, and are thought to assist in active stabilization through an internal rotatory action on the proximal tibia (Paulos et al. 1980). Laterally, the biceps femoris may affect external rotation of the tibia through the part of its insertion onto the lateral aspect of the proximal tibia (Cailliet, 1973). Together these medial and lateral inserting muscles contribute to the extensor mechanism alignment by changing the position of the tibial tubercle and its relationship to the patella and the femoral sulcus (James, 1979).

In summary, the static and dynamic elements of stabilization must function together for normal patellofemoral mechanics.

Biomechanics of the Patellofemoral Joint

One of the major functions of the patella is to increase the extensor force of the quadriceps muscle. It does this by increasing the distance between the axis of motion at the femoral condyle and the quadriceps tendon, thereby increasing the extensor moment arm. Ficat and Hungerford (1977) report that throughout the entire range of motion of the knee, the patella increases the force of the quadriceps by as much as 50%, depending on the amount of knee flexion.

Another major function of the patella is that it centralizes the divergent forces from the quadriceps and distributes these forces through the patellar tendon to the tibia and through the articular cartilage of the patella to the femur. Patellofemoral joint reaction forces, with the superimposed load of activity plus the torque generated by the quadriceps, can become as high as three times body weight with stair-climbing and eight times body weight in squatting (James, 1979). These high loads compress the articular cartilage between an area of patellofemoral contact which James (1979) reports is never more than about one third of the patellar articular surface at any given range of motion.

The patellofemoral joint reaction forces are also affected by the configuration of the patella. The portion of the articular surface that shows the most variation is the medial facet (Ficat and Hungerford, 1977). When this facet is smaller or differently shaped, the joint reaction forces are increased which overloads the articular cartilage of the medial facet. However, approximately 65% of the population have normally shaped patellae and their joint reaction forces are normally distributed over the contact surface of the patella. (James, 1979).

Clinical Features

Patellofemoral pain syndrome (PFPS) is described as a diffuse, poorly located pain around the patella which arises from abnormal tracking of the patella (Grana et al. 1984). It may be referred to as peripatellar syndrome, patellar malalignment, patellofemoral arthralgia, or runner's

knee, however it is clinically differentiated from chondromalacia patellae in that chondromalacia implies lesions of the retroarticular cartilage upon arthroscopic investigation (Bentley and Dowd, 1984).

It has been reported that PFPS affects teenage females and highly active athletes the most (Bentley and Dowd, 1984). However, other reports in the literature suggest that it relates to sports activity or trauma (Grana et al. 1984), and is equally common among both sexes (Reynolds et al. 1983).

The pain is often a dull, aching one that may be behind the patella, or along the medial border, or which may eventually radiate in all directions (Malek and Mangine, 1981). The pain may be aggravated by sitting with the knees bent for long periods (movie sign) or by activity which loads the patellofemoral joint during flexion (ie. - squatting, ascending or descending stairs). Swelling is not common but may be mildly present, there is no history of 'locking' as seen with meniscal tears, but the patient may complain of a sensation of 'giving way' of the knee. Crepitus may be present during movement of the patella and the patient will often note a stiffness or tightness at the knee, especially after activity. One may also note that compression of the patella against the femoral condyles will elicit pain.

Muscle testing may reveal weakness of the quadriceps and/or the hamstrings groups. The strength of the hamstrings has been found to be less than that of the quadriceps in a normal knee (Nosse, 1982). The relationship between the strength of the flexors to the extensors has been reported by Nosse (1982) to vary between 43-90%, depending upon the

angular velocity.

It has been suggested that the vastus medialis and the vastus lateralis should have equal strength so that they contribute to the correct alignment of the patella (Reynolds et al. 1983). In terms of quadriceps weakness, the literature presents different views. Mariani and Caruso (1979) have reported that quadriceps weakness is attributable specifically to vastus medialis weakness. However, Wild et al. (1982), believe that weakness of the quadriceps is not specific to the vastus medialis but rather indicative of weakness of all of the quadriceps.

Measurement of the Q-angle, which is the angle between the line of pull of the quadriceps and the patellar tendon, is often above 15° in patients with PFPS (Schamberger, 1983). A Q-angle above 15° may be indicative of lateral tracking of the patella (LeVeau & Bernhardt, 1984) but by itself the Q-angle is not diagnostic of PFPS. It is often associated with other deficiencies of the extensor mechanism.

Lower extremity alignment must be assessed as torsional or angular malalignments have a significant influence on the mechanics of the patellofemoral joint. James (1979) describes one group of torsional deformities that he has referred to as 'miserable malalignment'. Increased internal hip rotation (femoral neck anteversion) may be compensated for by external rotation of the tibia so that the feet are placed forward rather than in-toeing. This results in an increased Q-angle, as the tibial tubercle is externally rotated. These patients will often have genu varum and recurvatum, squinting patellae, a high riding patella (patella alta) and compensatory pronation of the foot.

Normal alignment of the knee is considered to be in slight valgus angulation (170°) as the femur is directed medially from the pelvis to articulate with the tibia. Angles much smaller or greater than 170° are considered to be abnormal and referred to as genu valgum or genu varum, respectively (Lehmkuhl and Smith, 1983). The presence of genu valgum may be associated with increased external rotation of the tibia or with compensatory pronation of the foot. In this situation, the Q-angle is increased by the external rotation of the tibia (LeVeau & Bernhardt, 1984).

Another relationship that must be evaluated is that of the function of the foot during walking and running, and its affect upon the knee and the patellofemoral joint in particular. As the speed of gait increases the magnitude of the forces through the lower extremity increases (Mann, 1982) and any biomechanical discrepancies that exist will also be amplified (Schamberger, 1983).

Normally as the foot strikes the ground there is a rapid period of pronation which reaches its maximum at approximately 35-45% of the stance phase in running (Smart et al. 1980). As the foot is pronating, the tibia is internally rotated and the knee is flexing. The pronated foot is a flexible one which is able to absorb shock and adapt to the ground surface (Lehmukuhl and Smith, 1983). At the same time, the knee flexion is also a shock absorbing mechanism (Winter, 1983). At approximately 70% of the stance phase, the foot supinates, the tibia externally rotates and the knee extends. If pronation of the foot and internal rotation of the tibia are prolonged into later stance when the knee is extending or if they are excessive, then there will be increased stress through the foot and an

increase in transverse rotation which must be absorbed at the knee. A disturbance in the tibiofemoral rotational relationship will cause abnormal joint stresses and will alter the patellofemoral mechanics (Bates et al. 1979).

A neutral foot is one that will function the most efficiently with least strain on the joints, ligaments, and tendons, and which requires minimal exertion by the muscles of the foot in stance (James, 1979). James also has observed from his clinical data that in a nonweight-bearing position (prone lying) the vertical axis of the heel should be parallel to the distal one third of the tibia, with the subtalar joint neutral (rearfoot alignment). Forefoot - heel alignment is considered normal when the plane of the metatarsal heads is perpendicular to the vertical axis of the heel. According to Taunton et al. (1985) normal rearfoot varus is considered to be 3° and forefoot varus 2° . Excessive or compensatory pronation of the foot in weight-bearing occurs when there is malalignment of the leg/heel relationship (increased rearfoot varus) or malalignment of the heel/forefoot relationship. In both cases the foot will overpronate to achieve contact with the ground (James et al. 1978).

Etiology of Patellofemoral Pain

A variety of factors have been suggested as possible causes of patellofemoral pain; among these are degenerative diseases, repeated minor trauma, acute severe trauma and malalignment of the patellofemoral extensor mechanism (Malek and Mangine, 1981). Reider et al. (1981) suggest that abnormal patellar tracking, secondary to malalignment of the

quadriceps-patellar mechanism, is a major etiological factor. James (1979) reports that in his experience, extensor mechanism malalignment is the most frequently implicated etiological factor. He also emphasizes the role of the lower extremity alignment in the etiology of patellofemoral joint problems.

James (1979) believes that the articular cartilage of the patella is a sensitive indicator of abnormal knee joint mechanics but he also adds that the development of pain is not directly from the articular cartilage, as it is devoid of pain fibres and blood vessels. Ficat and Hungerford (1977) suggest that in a normal diarthrodial joint there are two sources for the painful stimuli : the richly innervated synovium and the subchondral bone.

The integrity of the articular cartilage is essential to joint lubrication and biomechanical function, and to the nutrition of the cartilage itself. Articular cartilage nutrition is dependent upon diffusion of the nutrients from superficial to deep layers of the cartilage especially during periods of non-compression. Under compression the deeper fibres are less permeable and resist the interstitial flow of fluid. Varying degrees of compression also affects the proteoglycan component of the ground substance, so that fluid escapes from the articular cartilage when compressed but is reabsorbed during periods of non-compression. This is the basis for joint lubrication. As an advancing compressive load moves towards non-compressed areas, fluid is pushed along the leading edge. Decreased permeability of the articular

cartilage occurs under the load and a lubricating film is maintained on the surface, while the cartilage returns to normal permeability in non-compressed areas (James, 1979).

Ficat and Hungerford (1977) have shown under local anesthetic, that direct pressure on softened but intact articular cartilage reproduced the patient's patellofemoral pain, whereas pressure on firm, healthy cartilage was not detected by the patient. This has led them and others (James, 1979) to the hypothesis that early changes in the articular cartilage occur at deep layers and affect the energy-absorbing capacity of the cartilage, which results in abnormal transmission of forces to the subchondral bone, and ultimately to the development of pain.

Normal patellar contact with the femur passes from distal to proximal as the knee flexes. Up to 135° of flexion all of the cartilage articulates with the femur at some point in the range, except for the odd facet (Ficat and Hungerford, 1977). By 135° the medial facet lies free in the intercondylar groove and the odd facet contacts the medial femoral condyle. Kessler and Hertling (1983) point out that this very late contact makes the odd facet an area of non-articulation in most everyday activities, which may render the articular cartilage nutritionally deficient. This phenomenon would become important in the case of abnormal lateral tracking of the patella, which brings the odd facet into earlier contact with the medial condyle. Poor nutrition may cause the cartilage to be weakened and softened and as such it would be unable to tolerate the unaccustomed forces.

Other causes of articular cartilage breakdown may involve cartilage that is otherwise healthy and well-nourished, but is overloaded by excessive patellofemoral joint reaction forces. For example, this may occur in a patella with a smaller than normal medial facet, in which a small area is subjected to increased forces.

The lateral facet may also be affected by abnormally high joint reaction forces. One possible cause of increased lateral pressure is excessive tightening, thickening, or sclerosis of the lateral retinaculum (Ficat and Hungerford, 1977). These authors have reported that many dysplasias of the patella have been noted together with what they call excessive lateral pressure syndrome. They believe that greater than normal lateral pressure on the patella during growth may alter the shape of the patella, and ultimately, may lead to changes in the retroarticular cartilage. LeVeau & Bernhardt (1984) suggest, that when the lateral connective tissues are tight the medial soft tissues are stressed and stretched, which may result in pain and inflammation in those tissues.

Another source of pain, that is related to the well innervated synovium, may be impingement of plica (James, 1979). Plica is an extension of synovial tissue which can become compressed between one of the femoral condyles and the patella. It originates either medially or laterally, most often laterally, and extends to the other side of the patellofemoral joint, including the inferior fat pad. When it is chronically impinged it becomes thickened and the patient complains of pain and tenderness across the medial or lateral femoral condyle and a 'snapping' or 'catching' sensation.

The present-day knowledge concerning the mechanism of pain in PFPS suggests that an alteration in the mechanics of the patellofemoral joint may result in increased patellofemoral joint reaction forces which the articular cartilage and subchondral bone are unable to tolerate. Basmajian (1970) believes that due to joint pain one voluntarily inhibits movement, which results in weakness and possible atrophy of the surrounding muscles. However, in an attempt to explain the development of pain in a joint, Ficat and Hungerford (1977) caution that there is still considerable room for greater understanding of the pathophysiology of painful joints. There is also a need to recognize that the etiological factors of PFPS are numerous and multifactorial, and as such also may not be completely understood.

ELECTROMYOGRAPHY

Electromyography (EMG) is the graphical recording of the electrical activity of muscles. It represents the summation of all the muscle action potentials after being transmitted through the muscle tissues. Voluntary isometric contractions result in a non-linear increase in the integrated EMG activity (Vredenburg & Rau, 1973), however, there are many factors which affect the recording of the EMG signal, such as electrode placement, amount of subcutaneous fat, skin temperature, and/or muscle mass that allow considerable variability among subjects or between trials (Winter, 1984).

A biological amplifier for the recording of the EMG can use either surface electrodes or indwelling electrodes. The amplifier should conform to certain specifications in regard to the gain, input impedance, frequency response, and CMRR, so that it generates a 'clean' signal; one that is undistorted and free of artifacts or 'noise' (ISEK, 1980).

Surface EMG has a frequency range of 5 - 2000 Hz. The electrodes are placed closely together (no more than 5 cm. apart) as recommended by Komi and Buskirk (1970) over the motor point of the muscle or the muscle belly. Each electrode/skin interface has a finite impedance depending upon the thickness of the skin, cleanliness of the skin, area of the electrode surface and temperature of the electrode paste.

Perry (1981) and Perry et al. (1981) have suggested that surface electrodes represent group muscle activity or the common activity of a group of superficial muscles. Although they reported in 1981 that surface

electrodes reflect less than one tenth of the activity sensed by indwelling electrodes, Bouisset and Maton (1972) have reported a linear relationship between the output of surface electrodes and indwelling electrodes. However, more recently, Schwab et al. (1983) have recognized that surface electrodes are the practical choice over indwelling electrodes in that subject compliance to a study is improved. In fact, in their study comparing overground to treadmill running and the use of surface electrodes and indwelling electrodes, they found no significant difference in the temporal patterns of muscle activity.

Once the EMG signal has been collected and amplified, it is usually processed so that it may be more easily compared with other biomechanical signals. Linear envelope EMG is one method of processing that follows the trend of the EMG and closely resembles the shape of the tension curve. In other words, it bears some relationship to the biomechanics of movement (Winter, 1979). Winter (1984) also believes that linear envelope processing is the best method for producing an analog pattern that is reliable and reproducible.

To further improve the reliability of the EMG in gait analysis, the gait cycle time base is normalized to 100% and the linear envelope is averaged from a number of strides to obtain an ensemble average for each muscle for a certain group of subjects (Winter, 1984; Richards et al. 1985).

Some authors have used a maximum voluntary isometric contraction as a between-day and between-subject normalization method in EMG gait studies (Dubo et al. 1976). However, Yang and Winter (1983) have reported that

this is not the most reliable method of comparing amplitude measures. In 1984 Yang and Winter investigated four types of normalization, two of which were derived from isometric calibration and two of which were calculated from walking trials, to determine if the between-subject variability could be decreased. The latter two methods involved normalizing to the peak of the within-subject ensemble average or to the mean of the within-subject ensemble average. In both cases there was a large reduction of between-subject variability, however, it was at the expense of information that may have been obtained from the EMG amplitude measures. Therefore when the EMG amplitude is an integral part of a study normalizing to the ensemble average would reduce its significance.

BIOMECHANICAL STUDIES OF RUNNING

EMG studies, electrogoniometer and mechanical power analyses have contributed immensely to the knowledge of muscle and joint activity during running. For example, certain electrogoniometric investigations (Taunton et al. 1985) have described three dimensional angular motion at the knee and the foot during treadmill running. These investigators have elaborated on the timing and degrees of plantar flexion, dorsiflexion, eversion, inversion, abduction and adduction at the foot and knee flexion and extension, valgus and varus, and internal and external rotation during one gait cycle.

An EMG study of the muscle activity during treadmill running by Elliott & Blanksby (1979) revealed that the vastus lateralis, the vastus medialis and rectus femoris were all active at heel-strike with their peak amplitudes occurring between heel-strike and heel-off. At a speed of 3.5 m/s (approximately 12 km/h), the average integrated EMG of the vastus medialis had the highest amplitude and rectus femoris had the least amplitude of the three muscles. The vastus medialis and the vastus lateralis had decreasing muscle activity, from the peak in midstance to early swing. Rectus femoris activity had decreased by the onset of swing phase, but had another burst of activity during swing.

In another EMG study of running, Mann (1982) reported quadriceps activity for 50-60% of the stance phase in running. He also noted quadriceps activity at the end of swing phase, but unfortunately he did not distinguish among the various muscles within the quadriceps.

Mechanical power analyses of running (Winter, 1983; Robertson & Taunton, 1982; Robertson, in press) have shown strong eccentric extensor

muscle activity at the knee immediately after heel contact and up to midstance. From midstance to push-off the extensors worked concentrically. At push-off the extensors were still dominant but working eccentrically. From the results of the power analyses, it has been suggested that the quadriceps work eccentrically in early stance to control knee flexion as the foot hits the ground - a shock absorbing mechanism (Winter, 1983). Robertson & Taunton (1982) reported this extensor moment to range between 150-350 N.m and the energy absorption to range between 25-105 joules. From midstance to late stance the quadriceps were contracting concentrically as the knee extends in preparation for push-off. This concentric contraction dissipated 11-44 joules of energy. At the very end of stance phase a smaller eccentric contraction of the quadriceps decelerated the flexing knee according to Winter (1983). This negative work by the extensors absorbed approximately 11 joules of energy. During swing phase the results of the power analysis (Winter, 1983) showed a lack of contribution by the knee extensors to the forward swinging leg and foot.

The EMG data from Elliott & Blanksby (1979) provided evidence that the vastus medialis and the vastus lateralis were the most active quadriceps during early stance and therefore may be responsible for most of the shock absorption at the knee. Rectus femoris also contributed to this function but to a lesser extent. Their study showed that the vastus medialis and the vastus lateralis continued to be more active throughout the balance of the stance phase.

Elliott & Blanksby (1979) have reported the EMG activity in rectus femoris during swing as acting as a hip flexor. Power analyses of the hip

during running have not revealed a pattern that is consistent enough to be reported and therefore can not confirm the EMG results.

ISOKINETIC DYNAMOMETRY

The ability to measure muscle strength as it relates to functional activity is essential to our understanding of normal performance. Muscle strength can be defined as the ability of a single muscle or a muscle group to exert maximal force in a single voluntary effort (Knapik and Ramos, 1980) or as Murray et al. (1980) define it - it is the rotational component, or torque, produced by a muscle. This strength can be measured isometrically, which measures the muscle force only at a specific joint angle, or it can be measured under the dynamic conditions of isotonic or isokinetic activity.

Isokinetic muscle activity is a relatively new concept, which Hislop and Perrine, and Thistle and coworkers introduced in 1967. Perrine (1968) defined isokinetic exercise as exercise which occurs against a load which allows movement at a mechanically fixed rate of speed and offers resistance inherently proportional to the muscle's dynamic tension developing capacity at every point in its range. The accommodating resistance supplied by an electromechanical device, called an isokinetic dynamometer, allows for the continuously changing muscle tension that occurs with changing leverage throughout the movement. Since the late 1960's when an isokinetic dynamometer (Cybex) was introduced to North America it has been possible to study the mechanical properties of muscle under conditions of constant speed, in vivo. Such properties as the maximal force curve, the work, power, and endurance capacities of muscle have been measured concentrically.

Using the isokinetic dynamometer, researchers have studied the relationship between angular velocity and torque values during concentric contractions (Thortensson et al. 1976). These investigations have reaffirmed the classical force-velocity relationship, which states that as the velocity of muscle shortening increases the muscle force decreases.

Murray et al. (1980) studied 72 men, from 20-86 years, to determine their maximal isometric torque and maximal concentric isokinetic torques for the right quadriceps and hamstrings. Isometric strength was tested at 30°, 45° and 60°, while isokinetic strength was measured at 36°/s. Generally their findings were that the mean maximal torque values were highest for the youngest group of men (20-35 years) and that maximum strength decreased with increasing age. They also found that the mean maximum torque for the quadriceps was greatest at 45°, that the mean maximum torque for the quadriceps from the youngest group of men was 2,227 kg-cm (218.2 N.m) and that the hamstrings maximal torque ranged from 43-61% of the maximal quadriceps torque.

Studies in which the strength of the quadriceps and hamstrings have been determined in young women have been carried out by at least two groups of investigators. In these studies the subjects were non-athletic females, as the investigators were attempting to establish a base-line of normal data for that population.

Wyatt and Edwards (1981) studied 50 female subjects aged 25-34 years on the isokinetic dynamometer at velocities of 60°/s, 180°/s and 300°/s to determine the peak torques of their quadriceps and hamstrings. At 60°/s

the mean peak quadriceps torque was 79 ft-lb (107 N.m) and the mean peak hamstrings torque was 56 ft-lb (76 N.m). At 180°/s the values were 57 ft-lb (77 N.m) for the quadriceps and 45 ft-lb (61 N.m) for the hamstrings. At 300°/s mean peak quadriceps torque was 38 ft-lb (52 N.m) and mean peak hamstrings torque was 32 ft-lb (43 N.m). In order to relate to the functional activity of walking, these authors recommended a velocity between 200 and 300°/s on the isokinetic dynamometer, as they have reported that the knee extends at a velocity of 230°/s during walking. The angular velocity at the knee during running would therefore be much higher.

Dibrezzo et al. (1984) studied the peak torque of the quadriceps and hamstrings in 241 untrained females aged 18-28 years. Their testing was done at only one velocity - 60°/s. They found the mean peak torques to be 94.47 ft-lb (130 N.m) for the quadriceps and 51.94 ft-lb (71 N.m) for the hamstrings.

Investigators have also attempted to determine the ratio of peak concentric torque, or strength, between the quadriceps and hamstrings. Goslin and Charteris (1979) have suggested that this ratio is speed dependent. They found that at an angular velocity of 30°/s the quadriceps/hamstrings ratio is 2:1 (hamstrings/quadriceps or H/Q ratio .50). Moffroid et al. (1969) reported the same H/Q ratio at 23°/s and Dibrezzo et al. (1985) found the same ratio at 60°/s. However, Wyatt and Edwards (1981) reported the ratios to be .71 at 60°/s, .79 at 180°/s and .85 at 300°/s in young females and .72 at 60°/s, .78 at 180°/s and .83 at

300°/s for young men. They concluded from their results that the difference between the strength in the flexors and extensors decreases as the velocity increases, and that the ratios are similar for men and women in the same age group, with similar levels of activity, tested at the same angular velocity. In his review of 50 reports pertaining to the strength relationship of the knee flexors and extensors, Nosse (1982) concludes that there is not a fixed strength ratio that could be appropriate for each individual under all circumstances, which is contrary to the generally accepted guideline that the knee flexors should be 60% as strong as the ipsilateral knee extensors (Scudder, 1980).

Even more recently than the development of an isokinetic dynamometer to study concentric muscle activity, Komi (1973) reported that he had designed an isokinetic dynamometer to record both eccentric and concentric forces. From his study of forearm muscles using his isokinetic dynamometer, Komi found that as velocity of contraction increased the eccentric force increased and the concentric force decreased, also confirming the force-velocity relationship of muscle.

In North America an isokinetic dynamometer called the Kinetic Communicator Exercise System (KINCOM)* has been developed which measures concentric and eccentric muscle power, torque, and work. In a study of the reliability and validity of the KINCOM, Farrell and Richards (1986) focused on three of its primary functions: lever arm position, lever arm velocity, and force measuring systems. They found that the differences in the force measurements were 3.2% or less, the lever arm speed was within

* Med-ex of Canada, Inc., Coquitlam, B.C., Canada

1.5% of the target speed and there was no difference in position measurement. They concluded that the discrepancies between the KINCOM and the external measuring devices were small enough that they could be due to calibration error and were not due to inaccuracy of the KINCOM.

Up to now most of the information regarding dynamic muscle testing, which closely approximates muscle action in functional activities, has been gathered from concentric muscle testing. However, it would appear with the advent of newer isokinetic devices that information regarding maximal muscle strength, muscle agonist/antagonist relationships and ipsilateral and contralateral limb strength relationships may be studied eccentrically, and eccentric/concentric relationships within a muscle can also be identified.

Most important to a study of the muscles at the knee, are the mechanical properties of eccentric work because the knee muscles are primarily energy absorbers throughout the gait cycle (Winter, 1983). However, there is also concentric work by both the flexors and extensors during gait, which must not be overlooked if a thorough study is to be made.

BIBLIOGRAPHY

- Anderson, J.E., ed. Grant's Atlas of Anatomy. VIII Edition. Williams and Wilkins Co., Baltimore. 1983.
- Appen, E.L., Duncan, P.W. Strength relationship of the knee musculature: Effects of gravity and sport. J. of Orthopaedic and Sports Physical Therapy. 7: 232-235. 1986.
- Basmajian, J.V. Re-education of vastus medialis: A misconception. Archives of Physical Medicine and Rehabilitation. 51: 245-247. 1970.
- Basmajian, J.V. Muscles Alive. IV Edition. The Williams & Wilkins Co., Baltimore. 1979.
- Bates, B.T., Osternig, L.R., Mason, B.R., James, S.L. Functional variability of the lower extremity during the support phase of running. Medicine and Science in Sports. 11: 328-331. 1979.
- Bentley, G., Dowd, O. Current concepts of etiology and treatment of chondromalacia patellae. Clinical Orthopaedics. 189: 209-228. 1984.
- Berg, K., Blanke, D., Miller, M. Muscular fitness profile of female college basketball players. J. of Orthopaedic and Sports Physical Therapy. 7: 59-64. 1985.
- Bouisset, S., Maton, B. Quantitative relationship between surface EMG and intramuscular electromyographic activity in voluntary movement. American Journal of Physical Medicine. 51: 285-295. 1972.
- Cailliet, R. Knee Pain and Disability. F.A. Davis & Co., Philadelphia. 1974.
- Campbell, D.E., Glenn, W. Rehabilitation of knee flexor and knee extensor muscle strength in patients with menisectomies, ligamentous repairs, and chondromalacia. Physical Therapy. 62: 10-15. 1982.
- Clement, D.B., Taunton, J.E., Smart, G.W., McNicol, K.L. A survey of overuse running injuries. The Physician and Sports Medicine. 9: 47-58. 1981.
- Delagi, E.F., Perotto, A., Iazetti, J., Morrison, D. Anatomic Guide for the Electromyographer. Charles C. Thomas. Springfield. 1975.
- Dibrezzo, R., Gench, B.E., Hinson, M.M., King, J. Peak torque values of the knee extensor and flexor muscles of females. J. of Orthopaedic and Sports Physical Therapy. 7: 65-68. 1985.

- Dubo, H., Peat, M., Winter, D., Quanbury, A., Hobson, D., Steinke, T., Reimer, G. Electromyographic temporal analysis of gait: normal human locomotion. Archives of Physical Medicine and Rehabilitation. 57: 415-420. 1976.
- Elliott, B.C., Blanksby, B.A. The synchronization of muscle activity and body segment movements during a running cycle. Medicine and Science in Sport. 11: 322-327. 1979.
- Eloranta, V., Komi, P. Function of the quadriceps femoris muscle under the full range of forces and differing contraction velocities of concentric work. Electromyography and Clinical Neurophysiology. 21: 419-431. 1981.
- Farrell, M., Richards, J. Analysis of the reliability and validity of the kinetic communicator exercise device. Medicine and Science in Sports and Exercise. 18: 44-49. 1986.
- Ficat, R.P., Hungerford, D.S. Disorders of the Patellofemoral Joint. The Williams & Wilkins Co., Baltimore. 1977.
- Fox, T.A. Dysplasia of the quadriceps mechanism. Surgical Clinics of North America. 55: 199-226. 1975.
- Goslin, B.R., Charteris, J. Isokinetic dynamometry: Normative data for clinical use in lower extremity (knee) cases. Scandinavian Journal of Rehabilitation Medicine. 11: 105-109. 1979.
- Grana, W.A., Hinkley, B., Hollingsworth, S. Arthroscopic evaluation and treatment of patellar malalignment. Clinical Orthopaedics. 186: 122-128. 1984.
- Hallen, L.G., Lindahl, O. Muscle function in knee extension. Acta Orthopaedica Scandinavia. 38: 434-444. 1967.
- Hughston, J.C. Subluxation of the patella. J. of Bone & Joint Surgery. 50: 1003-1026. 1968.
- International Society of Electrophysiological Kinesiology. Units, Terms, and Standards in the Reporting of EMG Research. August 1980.
- James, S.L., Bates, B.T., Osternig, L.R. Injuries to runners. American Journal of Sports Medicine. 6: 40-50. 1978.
- James, S.L. Chondromalacia of the patella in the adolescent. In The Injured Adolescent Knee. p. 205-250. Edited by J.C. Kennedy. The Williams & Wilkins Co., Baltimore. 1979.
- Kessler, R.M., Hertling, D. Management of Common Musculoskeletal Disorders. p. 205-250. Harper & Row, Philadelphia. 1983.

- Knapik, J., Ramos, M. Isokinetic and isometric torque relationships in the human body. Archives of Physical Medicine and Rehabilitation. 61: 65-67. 1980.
- Komi, P., Buskirk, E. Reproducibility of electromyographic measurements with inserted wire electrodes and surface electrodes. Electromyography. 10: 357-367. 1970.
- Komi, P.V. Measurement of the force - velocity relationship in muscle under concentric and eccentric contractions. In Biomechanics III. p. 224-229. Karger. Basel. 1973.
- Komi, P.V. Relationships between muscle tension, EMG and velocity of contraction under concentric and eccentric work. In New Developments in Electromyography and Clinical Neurophysiology. p. 596-606. Edited by J.E. Desmedt. Karger, Basel. 1973.
- Lehmkuhl, L.D., Smith, L.K. Brunnstrom's Clinical Kinesiology. Edition 4. F.A. Davis, Philadelphia. 1983.
- LeVeau, B.F., Rogers, C. Selective training of the vastus medialis muscle using EMG biofeedback. Physical Therapy. 60: 1410-1415. 1980.
- LeVeau, B.F., Bernhardt, D.B. Developmental biomechanics. Physical Therapy. 64: 1874-1882. 1984.
- Lieb, F.J., Perry, J. Quadriceps function. An electromyographic study under isometric conditions. J. of Bone and Joint Surgery. 53A: 749-758. 1971.
- MacIntyre, D., Robertson, D.G.E. EMG profiles of the knee muscles during treadmill running. In Biomechanics X. In press.
- Malek, M.M., Mangine, R.E. Patellofemoral pain syndromes: A comprehensive and conservative approach. J. of Orthopaedic and Sports Physical Therapy. 2: 108-116. 1981.
- Mann, R.A. Biomechanics of running. Prevention and Treatment of Running Injuries. C.B. Slack, New Jersey. 1982.
- Mariani, P.P., Caruso, I. An electromyographic investigation of subluxation of the patella. J. Bone and Joint Surgery. 61-B: 169-171. 1979.
- Moffroid, M., Whipple, R., Hofkosh, J., Lowman, E., Thistle, H. A study of isokinetic exercise. Physical Therapy. 49: 735-746. 1969.
- Murray, M.P., Gardner, G.M. Mollinger, G.M. Sepic, S.B. Strength of isometric and isokinetic contractions. Physical Therapy. 60: 412-419. 1980.

- Nosse, L.J. Assessment of selected reports on the strength relationship of the knee musculature. J. of Orthopaedic and Sports Physical Therapy. 4: 78-84. 1982.
- Paulos, L., Rusche, K., Johnson, C., Noyes, F.R. Patellar malalignment. Physical Therapy. 60: 1624-1632. 1980.
- Perrine, J. Isokinetic exercise and the mechanical energy potentials of muscle. J. of Health and Physical Education 39: 40-44. 1968.
- Perry, J. EMG - Surface vs. wire. Physical Therapy. 61: 925-927. 1981.
- Perry, J. Easterday, C., Antonelli, D. Surface vs intramuscular electrodes for electromyography of superficial and deep muscles. Physical Therapy. 61: 7-15. 1981.
- Pocock, G. Electromyographic study of the quadriceps during resistive exercise. Physical Therapy. 43: 427-434. 1963.
- Reider, B., Marshall, J., Warren, R. Clinical characteristics of patellar disorders in young athletes. American Journal of Sports Medicine. 9: 270-274. 1981.
- Reynolds, L., Levin, T.A. Medeiros, J.M., Adler, N.S., Hallum, A. EMG activity of the vastus medialis oblique and the vastus lateralis in their role in patellar alignment. American Journal of Physical Medicine. 62: 61-70. 1983.
- Richards, C.L., Dynamic strength characteristics during isokinetic knee movements in healthy women. Physiotherapy Canada. 33: 141-150. 1981.
- Richards, C.L., Wessel, J., Malouin, F. Muscle activation patterns in gait of rheumatoid arthritic patients. Physiotherapy Canada. 37: 220-228. 1985.
- Robertson, D.G.E. Functions of the leg muscles during stance phase in running. In Biomechanics X. In press.
- Robertson, D.G.E., Taunton, J.E. Power characteristics of leg muscles during stance phase of running. Proceedings of the Second Biannual Conference of the Canadian Society for Biomechanics, 1982.
- Schamberger, W. Orthotics for athletes: Attacking the biomechanical roots of injury. Canadian Family Physician. 29: 1670-1680. 1983.
- Schwab, G.H., Moynes, D.R., Job, F.W., Perry, J. Lower extremity electromyographic analysis of running gait. Clinical Orthopaedics. 176: 166-170. 1983.

- Smart, G.W., Taunton, J.E., Clement, D.B. Achilles tendon disorders in runners. Medicine and Science in Sport and Exercise. 12: 231-243. 1980.
- Taunton, J.E., Clement, D.B., Smart, G.W., Wiley, J.P., McNicol, K.L. A triplanar electrogoniometer investigation of running mechanics in runners with compensatory overpronation. Canadian Journal of Applied Sport Sciences. 10: 104-115. 1985.
- Vredenburg, J., Rau, G. Surface electromyography in relation to force, muscle length and endurance. In New Developments in Electromyography and Clinical Neurophysiology. p. 607-622. Edited by J.E. Desmedt. Karger. Basel. 1973.
- Wiberg, G. Roentgenographic and anatomic studies on the femoropatellar joint. Acta Orthopaedica Scandinavia. 12: 319-410. 1941.
- Wild, J., Franklin, T., Woods, G. Patellar pain and quadriceps rehabilitation. American Journal of Sports Medicine. 10: 12-15. 1982.
- Winter, D.A., Biomechanics of Human Movement. John Wiley & Sons, New York. 1979.
- Winter, D.A. Movements of force and mechanical power in jogging. J. of Biomechanics. 16: 91-97. 1983.
- Winter, D.A. Pathologic gait diagnosis with computer-averaged electromyographic profiles. Archives of Physical Medicine and Rehabilitation. 16: 91-97. 1984.
- Wyatt, M.P., Edwards, A.M. Comparison of quadriceps and hamstring torque values during isokinetic exercise. J. of Orthopaedic and Sports Physical Therapy. 3: 48-56. 1981.
- Yang, J.F., Winter, D.A. Electromyography reliability in maximal and submaximal isometric contractions. Archives of Physical Medicine and Rehabilitation. 64: 417-420. 1983.
- Yang, J.F., Winter, D.A. Electromyographic amplitude normalization methods: improving their sensitivity as diagnostic tools in gait analysis. Archives of Physical Medicine and Rehabilitation. 65: 517-521. 1984.