ABSTRACT

FROEHLING, L. A. Effectiveness of exercise versus exercise plus tape in the management of females with patellofemoral pain. MS in Exercise and Sport Science-Human Performance, May 1996, 77pp. (M. Miller)

The difference among no treatment, use of traditional physical therapy exercises, and use of the same exercises plus patellar taping was investigated. Thirty female Ss (ages18-43) with nontraumatic onset of knee pain of at least 6 week duration were assigned to an exercise, exercise plus tape, or control group. Ss in the exercise and exercise plus tape groups were instructed in flexibility and strengthening exercises which were progressed over 8 weeks. Ss in the exercise plus tape group also performed patellofemoral taping based on McConnell principles for 2 to 4 weeks. Data were gathered on subjective reporting of symptoms with the Hughston Sports Medicine Foundation, Inc.: Initial Knee History, symptom reproduction with performance of a functional activity, McConnell patellofemoral orientation, and surface electromyography of vastus medialis oblique (VMO) and vastus lateralis (VL) recruitment and ratio. The results indicated that Ss in the exercise plus tape group reported a significant decrease in subjective symptoms and progressed to painfree functional activities and improved VMO recruitment more quickly than subjects who used exercise alone, or those who received no treatment. The mechanism for this change was unclear but did not appear to be related to PF orientation or VMO:VL ratio which did not differ between groups or change over time.

EFFECTIVENESS OF EXERCISE VERSUS EXERCISE PLUS TAPE IN THE MANAGEMENT OF FEMALES WITH PATELLOFEMORAL PAIN

A MANUSCRIPT STYLE THESIS PRESENTED

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INTRODUCTION

Patellofemoral pain is one of the most common knee complaints encountered in sports medicine clinics.[1] The actual incidence in the general population is not known. It is however thought to occur at a higher incidence in athletes and females.[2]

Overall, there is lack of agreement between health care providers as to the best term for this condition. Some of the names used include anterior knee pain, patellalgia, patellofemoral pain syndrome, patellar compression syndrome, lateral compression syndrome, patellar malalignment syndrome, patellar subluxation, quadriceps or vastus medialis oblique (VMO) insufficiency, and runner's knee. The term "chondromalacia" was also used in some articles. This term however, refers to a specific condition where some visually diagnosed pathology such as softening or erosion of articular cartilage is found. Therefore, since arthroscopic examination is rarely used in the initial diagnosis of anterior knee pain, the term is probably being used inappropriately.

The term patellofemoral pain syndrome (PFPS) was selected by this author for use due to the common subjective and objective findings in the absence of a known cause or pathology. PFPS may be characterized by the following: dull aching pain which is usually vague in location, often described as around or under the patella; symptoms are aggravated with walking, running, ascending or descending stairs, or prolonged sitting (positive movie sign); pain with squatting or kneeling; also of the leg buckling, giving way, or presence of crepitis.[2]

The causes of PFPS are not completely understood, but are generally thought to be secondary to patellofemoral malalignment. Possible causes of patellofemoral malalignment are numerous, and include faulty lower extremity alignment and kinematics, extensor mechanism dysfunction, and flexibility and strength deficits of the lower extremities. Lower extremity alignment and kinematic faults include excessive pronation[3]; genu recurvatum, genu varum, and genu valgum[4]; increased Q-angle[5]; femoral anteversion and external tibial rotation[6]; and faulty patellar orientation during static and dynamic assessment.[7,8] Extensor mechanism dysfunction can result from quadriceps atrophy, particularly the VMO[9]; or faulty recruitment of the quadriceps musculature during activation.[10] Another factor that may cause patellofemoral malalignment is faulty flexibility and muscular strength of the lower extremity. The most often considered muscles which lack necessary flexibility include the iliopsoas, iliotibial band, rectus femoris, hamstrings, and gastroc-soleus group.[11] Strength of the gluteus medius,[11] gluteus maximus, and trunk extensors[12] are also factors that should be assessed.

The treatment of PFPS remains somewhat controversial. Conservative rehabilitation has been found to bring relief of symptoms to the majority of patients with PFPS.[1,7,13-17] Conservative treatment may involve a combination of techniques including rest; medication; ice; bracing; exercise programs for stretching, strengthening and muscle reeducation; and patellar taping.

Doucette and Goble[1] found that a comprehensive program of exercise to address deficits found on physical examination of patients with lateral c ..pression syndrome did indeed result in decreased pain and improved patellar tracking. McConnell[7] has suggested the use of patellar taping in addition to the comprehensive exercise program. The suggested rationale is that patellar taping will improve patellar tracking, thereby decreasing the potential for pain and swelling which may cause VMO inhibition. Taping may also improve active recruitment of the VMO by restoring a more normal length tension ratio in the VMO.[7]

Therefore, the purpose of this study was to determine if there was a difference in the effect of using exercise alone versus exercise and patellar taping on the subjective reporting of pain, symptoms with functional activities, patellar orientation, and quadriceps recruitment and ratio in females with PFPS. The techniques used for data collection on patellar orientation and surface electromyography (EMG) activity were selected due to their common use in clinical practice. It was hoped that this would add to the clinical relevance of the results and application. However, these data collection techniques may have contributed to errors in the interpretation of the findings.

METHODS AND PROCEDURES

Subjects

Thirty female volunteers with either unilateral or bilateral knee pain participated in the study. The subjects' ages ranged from 18 to 43 years of age (X = 25.9, SD = 8.8). Knee complaints must have been present for a minimum of 6 weeks, and be able to be reproduced at the time of the initial evaluation. Individuals who had a history of knee surgery, fracture or significant soft tissue injury to the involved extremity, had diagnosed intra-articular pathology, significant ankle problems, or had received treatment for their knees within the past 6 months were excluded from the study. All subjects gave written informed consent prior to participation (see Appendix A).

Tester

The tester in this study was a physical therapist employed in an outpatient orthopaedic department. The tester frequently treated patients with knee disorders or PFPS in her department. The tester had attended Level I and Level II McConnell Patellofemoral Taping courses. She had also been an assistant at a Level I McConnell Patellofemoral Taping course.

Evaluation Procedure

Prior to starting the study, each subject was evaluated. The evaluation included the following: subjective reporting of pain, identification of a functional activity which reproduced the subject's pain, evaluation of patellar orientation, and EMG assessment of quadriceps recruitment and ratio. When subjects reported bilateral pain, the most severely involved leg of the subject was tested. In addition, lower extremity range of motion, flexibility, and strength were assessed in order to assist with appropriate home exercise program instruction for each subject.

Subjective Reporting of Pain

Subjects filled out a 36 question subjective knee disorders analysis form which asked subjects about subjective problems as well as objective functions. The form was The Hughston Sports Medicine Foundation, Inc.: Initial Knee History (Hughston VAS).* [18] Subjects responded by shading in the appropriate box that ranged from best (0) to worst (10). All responses were totaled to get an overall score. Therefore, the lower the score, the less pain and limitation in activity. Likewise, the higher the score, the more pain and limitation in activity. It also asked subjects to identify their current, preproblem, and

* The Hughston Clinic, P.C., 6262 Hamilton Road, P.O. Box 9517, Columbus, GA 31908-9517.

desired posttreatment activity level by selecting one of seven categories ranging from crutches or external support required (score of 0) to highly competitive activities (score of 6).

Identification of Functional Indicator

Subjects were asked to perform a series of functional movements and to report which activity reproduced their symptoms. The functional movements were considered progressive in difficulty and were as follows: walk, double leg squat, single leg squat, step up onto an 18.5 cm step, or step down from an 18.5 cm step. Symptom reproduction was required for participation in the study. The easiest activity which reproduced the subjects' symptoms was recorded as her functional indicator.

Patellar Orientation

Subjects were positioned supine and patellar orientation was assessed using McConnell patellofemoral alignment tests.[7,8] The subject's knee was marked as needed and evaluated using a tape measure and palpation. The patellofemoral alignment tests used were as follows: glide - static, glide - dynamic, lateral tilt - static, lateral tilt - dynamic, rotation - static, anteroposterior tilt - static, and anteroposterior tilt - dynamic.

Quadriceps Electromyography Activity

Surface EMG activity of the vastus medialis oblique (VMO) and vastus lateralis (VL) portions of the quadriceps was assessed with the use of the Myoexerciser III† which is a clinical EMG unit. After preparing the skin by clensing with isopropyl alcohol, two sets of three disposable silver/chloride surface electrodes were positioned as follows. One set of electrodes was

† Verimed International, Inc., 11950 N.W. 39th St., Suite D, Coral Springs, FL 33065-2564.

placed 3 cm proximal and medial to the superior medial pole of the patella over the VMO. The other set of electrodes was placed 5 cm proximal and lateral to the superior lateral pole of the patella over the VL. The active electrodes were placed in series with the muscle belly. The ground electrode was positioned with the active electrodes on either side to ensure consistency in application.

Subjects were positioned in sitting with the lower leg hanging free. They were asked to perform active knee extension from approximately 90 degrees of flexion to 0 degrees of extension. Timing of the contraction was coordinated with the timer of the Myoexerciser III display as it counted up to ten. The tester prepared the subject by saying "ready" on the count of four and "go" on the count of five. The VMO and VL recruitment pattern was identified as VMO first if the VMO fired first, VMO second if the VMO fired second, or VMO:VL same if the VMO and VL fired at the same time. The average EMG output from a 5 second contraction, with approximately the last 2 seconds being an isometric hold at end range, was also recorded. The recorded EMG values from the VMO and VL were used to calculate the VMO:VL ratio.[19]

A copy of the Patellofemoral Pain Evaluation data collection form is included in Appendix B.

<u>Experimental Procedure</u>

Subjects were assigned to one of three groups based on their patellofemoral alignment tests. The scores from the glide - static, lateral tilt - static, and anteroposterior - static were added together and the dynamic code carried through to get a patellar alignment score. For example, a knee with normal patellar alignment would have a score of 0, and a knee with the worst alignment would have a score of 5+++. Subjects were listed in descending order according to their patellar alignment score. The top three subjects were randomly assigned to one of three groups. Successive sets of three were treated similarly until all subjects were assigned to a group.

Group one was identified as the exercise group, group two as the exercise plus tape group, and group three as the control group. The exercise and exercise plus tape groups were instructed in an individualized, comprehensive exercise program designed to meet their specific needs based on deficits found during the physical examination. Exercise programs consisted of exercises taken from the following categories: Instruction in proper lower extremity mechanics during functional activities to avoid excessive patellofemoral compression forces, VMO reeducation/strengthening exercises to be performed with emphasis on VMO recruitment progressing from open chain to closed chain, quadriceps and general lower extremity strengthening, general lower extremity flexibility, and lateral retinaculum stretches using manual techniques. Specific exercises in each category are outlined in Appendix C. Subjects were provided with written instructions, and were asked to perform the exercises one time per day. Subjects were instructed to avoid patellofemoral pain and swelling due to potential reflex inhibition of the VMO.[20]

Subjects in the exercise plus tape group were also instructed in patellofemoral taping. Subjects were instructed to tape their knees, using McConnell[7,8] taping techniques, based on the specific patellar position found in the physical examination. Subjects were instructed to tape their knees, using McConnell [7,8] taping techniques, based on the specific patellar position found in the physical examination. Subjects were asked to tape daily for the first 2 weeks. Subjects were supplied with taping kits‡ and written instructions. Instructions were also provided on the purpose of taping, guidelines, skin care, and weaning off the tape (see Appendix D).

Subjects in the control group were instructed to continue their current level of daily activities and to avoid changing any activities that might influence their knee symptoms. Subjects in the exercise and exercise plus tape group were seen during weeks 2, 4, and 6 for instructions in appropriate exercise progression. Subjects in the exercise plus tape group were also instructed in tapering off the tape as indicated based on guidelines established by McConnell.[8]

Subjects in all three groups were seen for a reevaluation during week 4 and for a final evaluation during week 8. The reevaluation included the same components as the initial evaluation: subjective reporting of pain, identification of a functional activity which reproduced the subject's pain, evaluation of patellar orientation, and EMG assessment of quadriceps recruitment and ratio. Subjects in the exercise plus tape group did not wear tape during the reevaluations.

At the conclusion of the study, all subjects in the control group were instructed in exercises and taping, supplied with written instructions and taping kits, and offered one to three follow-up sessions.

Data Analysis

An ANOVA was used to compare subject's age at week 1. An ANOVA was also used to compare subjective pain rating and EMG VMO:VL ratio between the groups at weeks 1, 4, and 8. An ANOVA was used to compare

‡ Beiersdorf Inc., Norwalk, CT 06856-5529.

changes in subjective pain rating and EMG VMO:VL ratio between groups over time (week 1 to 4 and week 1 to 8). The alpha level was set at $p = .05$. A Tukey's Honestly Significant Difference (HSD) Test was used to perform post hoc comparisons when needed ($p = .05$).

Chi-square analysis was used to compare side of involvement at week 1, and to compare the following dependent variables at weeks 1,4, and 8: the ability to reproduce symptoms with a functional activity, subjective rating of current activity level, activity level before the knee problem, activity level desired after treatment, four static patellar orientation tests, three dynamic patellar orientation tests, and EMG firing pattern. Chi-square analysis was also used to look at these variables between groups over time (week 1 to 4 and week 1 to 8). The alpha level was set at $p = .05$. Post hoc comparisons were done using chi-square ($p = .05$). The SAS statistical package[§] was used for all analyses.

RESULTS

There was no difference ($p > .05$) between the groups for age or side of involvement. See Table 1 for descriptive data.

Subjective Reporting of Pain

Subjective responses to the 36 question Hughston VAS were totaled by subject at weeks 1, 4, and 8. Mean values for the totaled score by group across time are recorded in Figure 1.

No difference ($p > .05$) was found between the groups at weeks 1 and 4. A difference ($p = .04$) was found between the groups at week 8. However, when looking at post hoc comparisons, the differences between each pair were not significant enough to meet the more stringent criteria of a Tukey's HSD.

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§ SAS Statistical Software Inc.

Table 1. Number of Subjects, Mean Age, and Side of Knee Involvement by Group.

Group Number	Group Name	N	Age (x ± SD)	Involved Knee Left	Involved Knee Right
1	Exercise	10	26.9 ± 9.17	3	7
2	Exercise + Tape	10	24.0 ± 7.36	4	6
3	Control	10	25.2 ± 14.47	6	4

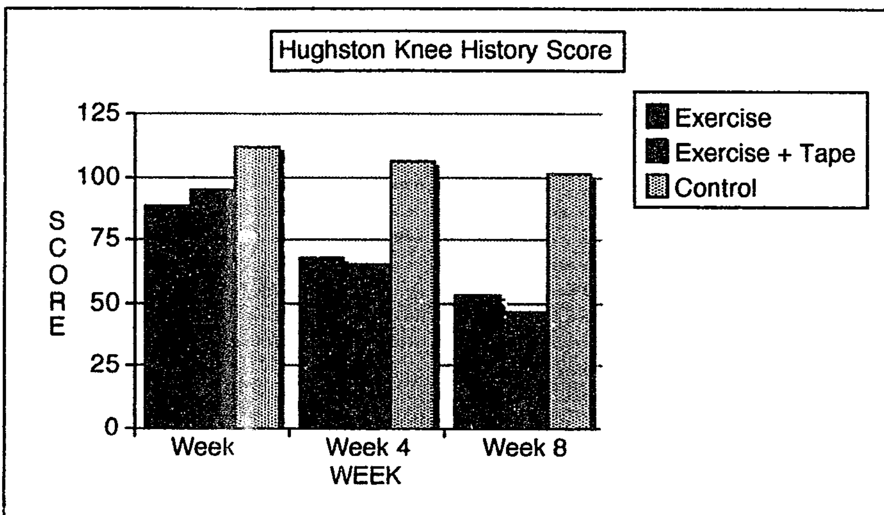

Figure 1. Hughston Sports Medicine Foundation, Inc.: Initial Knee History mean totaled score by group across time.

No difference ($p > .05$) was found between the groups from week 1 to 4.

A difference was found between the groups from week 1 to 8. A Tukey's HSD Test indicated that the exercise plus tape group had a significant ($HSD = 34.069$, $df = 27$, $p < .05$) decrease in mean subjective response. No difference was found in the exercise or control groups.

When analyzing the change in subjective response from week 1 to 8, all of the subjects (100%) in both the exercise (mean decrease of 35) and the exercise plus tape (mean decrease of 49.1) groups reported a decrease in their symptoms. Eight of the 10 subjects (80%) in the control group (mean decrease of 10.7) reported a decrease in their symptoms. While all the groups subjectively reported overall decreases in their symptoms, only the exercise plus tape group had a significant decrease as noted above.

Subject's subjective rating of their current activity level, activity level before knee injury/problem, and activity level desired after treatment for knee problems did not differ ($p > .05$) between the groups or change over time.

Functional Indicator

Symptom reproduction while performing a functional movement was required in order to participate in the study. This same movement was tested at the 4 and 8 week recheck. Provocation of symptoms from easiest to hardest was as follows: walk, double leg squat, single leg squat, step up, step down. A comparison was made as to whether it took the same or easier movement to reproduce symptoms, an indication of no improvement, or whether it took a harder movement to reproduce symptoms, an indication of improvement. Results are shown in Table 2.

A difference ($p = .054$) was found between the groups at week 4, indicating a change occurred from week 1 to 4. The post hoc test indicated that there was a difference (p = .025) between the exercise plus tape group and control groups. No difference was found between the exercise and control group (p = .074) or exercise and exercise plus taping groups (p = .606).

Table 2. Change in Performance of a Functional Indicator (Walk, Double Leg Squat, Single Leg Squat, Step Up, Step Down) by Group Across Time.

Group	Week 1		Week 1 to 4		Week 4 to 8	
	Imp	No Imp	Imp	No Imp	Imp	No Imp
Exercise	-	10	7	3	7	3
Exercise + Tape	-	10	8	2	9	1
Control	-	10	3	7	2	8

A comparison of the groups at week 8 also indicated a difference (p = .004) between the groups indicating a change occurred from week 1 to 8. Post hoc tests found a difference between the exercise plus tape and control groups (p = .002) and between the exercise and control groups (p = .025). No difference was found between the exercise plus tape and exercise groups (p = .264). The difference between the exercise and control groups at week 8 occurred due to the control group changing to include more subjects in the no improvement category, and not due to exercise group subjects moving into the improvement category.

Patellar Orientation

Between group comparisons of each of the seven patellar orientation tests were carried out using chi-square. Chi-square results at weeks 1, 4, and 8 are listed in Table 3.

Table 3. Chi-Square Values for Between Group Comparisons of Patellar Orientation Tests at Weeks 1, 4, and 8.

Patellar Orientation Tests	Week 1	Week 4	Week 8
Glide Static	.659	.585	.202
Glide Dynamic	.861	.329	.315
Tilt Static	.670	.175	.380
Tilt Dynamic	*	*	*
Rotation Static	.396	.237	.617
Anteroposterior Static	.334	.396	.392
Anteroposterior Dynamic	*	*	*

*Unable to calculate chi-square as all subjects in all groups scored the same.

No difference ($p > .05$) was found between the groups at weeks 1, 4, or 8 on any of the variables.

A within group comparison of the seven patellar orientation tests from week 1 to 8 found no change ($p > .05$) in patellar orientation. Chi-square results by group are reported in Table 4.

Quadriceps Electromyography

The EMG activity of the VMO and VL was monitored for 5 seconds during an active knee extension from approximately 90 degrees of flexion to 0 degrees of extension. The average EMG output during the 5 second contraction was recorded using the Myoexerciser III EMG unit.

Table 4. Chi-Square Values for Between Group Comparisons of Patellar Orientation Tests From Week 1 to 8 by Group.

Patellar Orientation Tests	Group		
	Exercise	Exercise + Tape	Control
Glide Static	.091	.880	.527
Glide Dynamic	.747	.016	*
Tilt Static	*	.170	*
Tilt Dynamic	*	*	*
Rotation Static	*	*	*
Anteroposterior Static	*	.135	*
Anteroposterior Dynamic	*	*	*

*Unable to be calculated due to column sum equal to zero.

Electromyography Firing Pattern

Each subject's EMG firing pattern was recorded as VMO first if the VMO fired first, VMO second if the VMO fired second, and VMO:VL same if the VMO and VL fired at the same time. Pattern of EMG firing at weeks 1, 4, and 8 are shown in Table 5. The number of subjects with each type of firing pattern within each group are graphed over time in Figures 2, 3, and 4.

No difference was found between the groups at week 1 ($p = .563$) or at week 4 ($p = .274$). A difference ($p = .035$) was found at week 8 with both exercise and the exercise plus tape groups having a better (VMO first) firing pattern than the control.

Table 5. The Number of Subjects with Each Type of Firing Pattern Within Each Group at Weeks 1, 4, and 8.

	Group		
Week	Exercise	Exercise + Tape	Control
Week 1			
VMO First	6	5	4
VMO Second	4	4	4
VMO:VL Same	0	1	2
Week 4			
VMO First	3	3	4
VMO Second	6	2	4
VMO:VL Same	1	5	2
Week 8			
VMO First	6	6	0
VMO Second	1	2	4
VMO:VL Same	3	2	6

Analysis of the change in EMG firing from week 1 to 4 and from week 1 to 8 for each group was also completed. An EMG response of VMO first at week 1 and VMO first at week 4 or 8 was categorized as best. EMG response of VMO second or VMO:VL same at week 1 and VMO first at week 4 or 8 was categorized as improved. All other combinations were categorized as not improved. See Tables 6 and 7 for distribution of EMG firing categories for week

1 to 4 and for week 1 to 8.

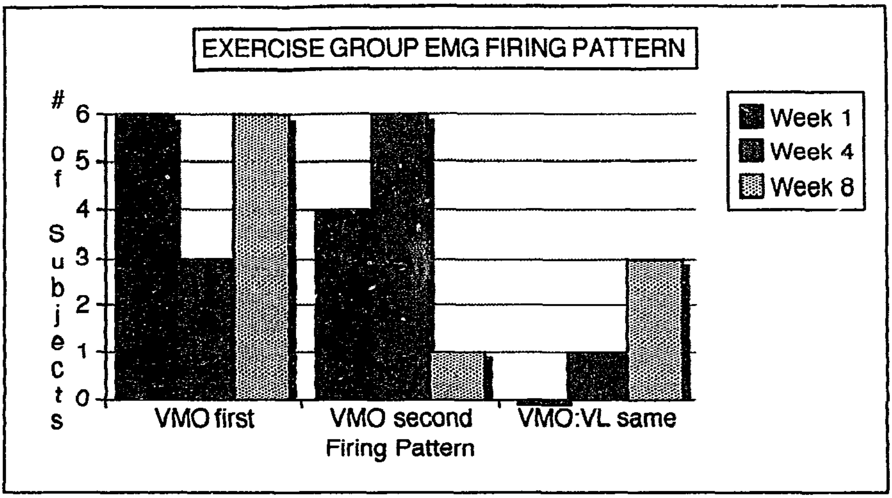

Figure 2. Frequency distribution of type of firing pattern in the exercise group over time.

No difference was found between the groups from week 1 to 4. A difference ($p = .040$) was found between the groups from week 1 to 8. Of the 20 subjects in both the exercise and exercise plus tape groups, 12 (60%) were categorized as best or improved compared to 0 (0%) of the 10 subjects in the control group.

Electromyography Ratio

The EMG ratio was calculated by dividing the VMO EMG value by the VL EMG value. The ratio represented VMO activity relative to the VL. This resulted in a mean calculated VMO value. If the value was greater than one, the VMO

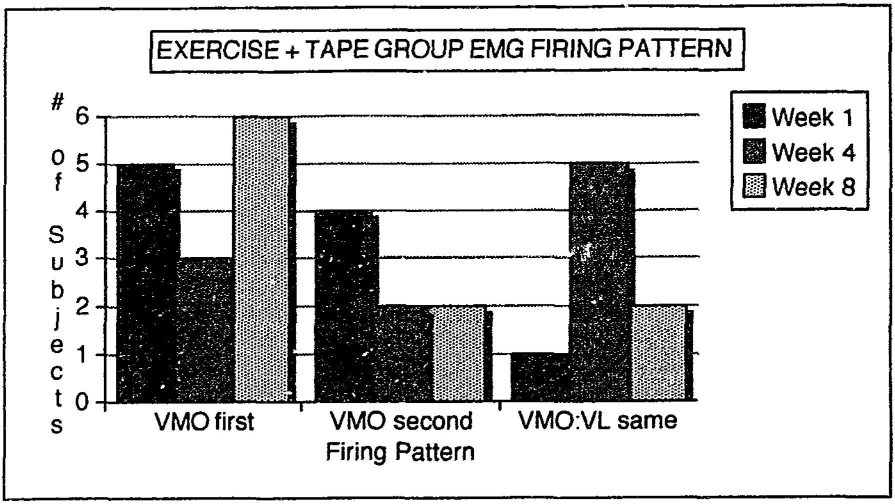

Figure 3. Frequency distribution of type of firing pattern in the exercise plus tape group over time.

was stronger. If the value was less than one, the VMO was weaker. Analysis of variance was done on the mean calculated VMO value. The mean and standard deviations at weeks 1, 4, and 8 are shown in Table 8. No difference was found between the groups at weeks 1 ($p = .14$), 4 ($p = .98$), or 8 ($p = .33$).

The change in calculated VMO value from week 1 to 4 and from week 1 to 8 for each group was also analyzed. The mean change in calculated VMO and standard deviations are recorded in Table 9. No difference was found in the change in calculated VMO value between the groups from weeks 1 to 4 ($p = .33$) or weeks 1 to 8 ($p = .07$). The change from weeks 1 to 8 was marginally significant and therefore the mean calculated values from Table 8 were plotted to look at the overall change between the groups. See Figure 5.

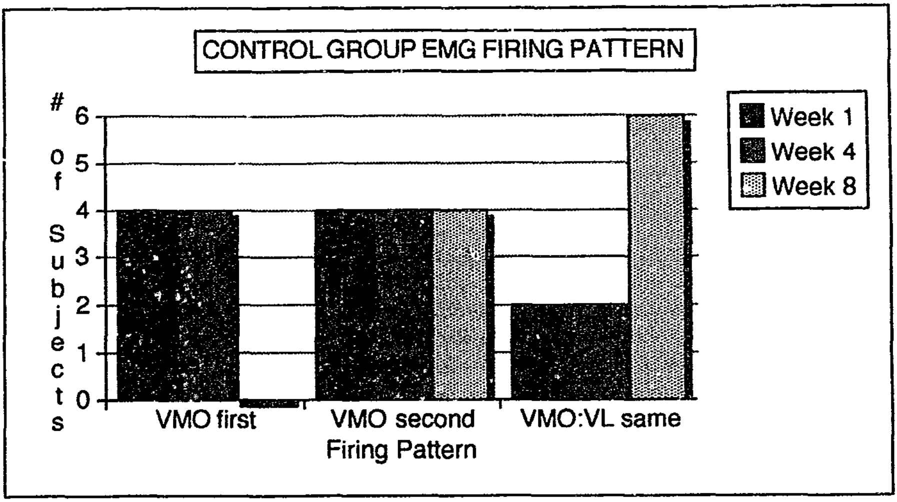

Figure 4. Frequency distribution of type of firing pattern in the control group over time.

Table 6. Change in EMG Firing Pattern from Week 1 to 4 by Group.

	Exercise	Exercise + Tape	Control
Best	2	1	2
Improved	1	2	2
Not Improved	7	7	6

While not significant, the exercise group made consistent improvement in the mean calculated VMO value. The control group made no change and the exercise plus tape group improved initially from week 1 to 4 but then declined

Table 7. Change in EMG Firing Pattern from Week 1 to 8 by Group.

	Exercise	Exercise + Tape	Control
Best	3	3	0
Improved	3	3	0
Not Improved	4	4	10

Table 8. Mean Calculated VMO Value and Standard Deviation at Weeks 1, 4, and 8 by Group.

Group	Week 1	Week 4	Week 8
Exercise	0.95 ± 0.21	1.14 ± 0.21	1.33 ± 0.51
Exercise + Tape	1.10 ± 0.26	1.17 ± 0.53	1.06 ± 0.31
Control	1.17 ± 0.27	1.16 ± 0.27	1.18 ± 0.34

from week 4 to 8 to a level less than at week 1. There appeared to have been a trend developing, which may have become significant if the study had been carried out for more than 8 weeks.

DISCUSSION

While 100% of the subjects in the exercise and exercise plus tape groups, and 80% of the subjects in the control group subjectively reported a decrease in symptoms, only the exercise plus tape group reported a decrease

Table 9. Mean Change in Calculated VMO Value and Standard Deviation from Week 1, to 4, and from Week 1 to 8.

Group	Week 1 to 4	Week 1 to 8
Exercise	0.19 ± 0.18	0.37 ± 0.59
Exercise + Tape	0.07 ± 0.36	- 0.03 ± 0.28
Control	- 0.02 ± 0.35	0.01 ± 0.35

* A positive number indicated improvement in VMO firing, a negative number indicated a decrease in VMO firing.

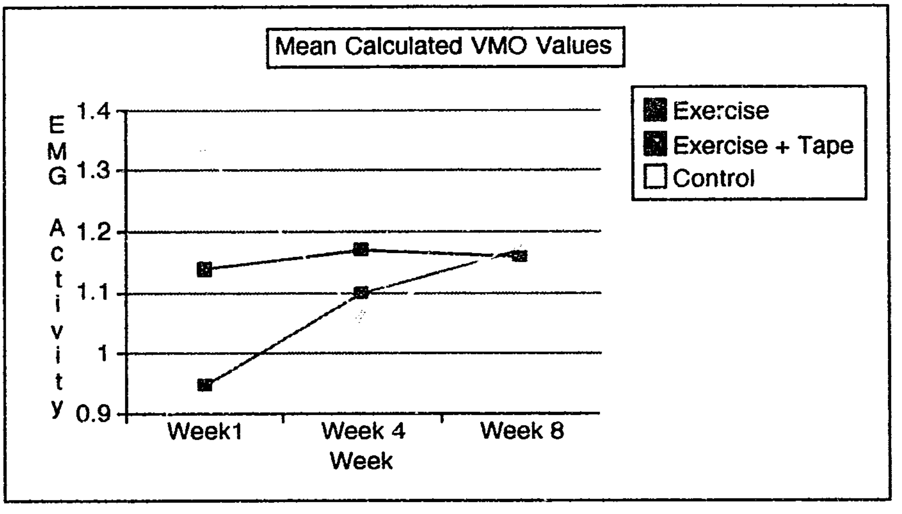

Figure 5. Mean calculated VMO values plotted against week 1, 4, and 8 by group.

that was considered significant. Also, only one subject in the exercise group scored a 0 at the end of the study, indicating no pain or limitation in function due to knee symptoms. This differs from previous studies in which Doucette and Goble[1] reported that 84% of subjects treated with exercise for an average of 8 weeks, or 11 physical therapy visits, were reported to be painfree. Similarly, McConnell[7] reported that 83% of subjects treated with exercise plus taping reported being painfree after three to eight treatment sessions. Comparison with these studies is difficult for the following reasons. The above cited studies did not include a description of the subjective scale that was used to measure the subject's pain response. Secondly, the Hughston VAS[18] is a relatively new and complex assessment of subjective knee complaints. The Hughston VAS includes an assessment of not only pain, but also what effect their knee symptoms have on their performance of functional tasks. Therefore, subjects would need to be painfree in nearly all functional movements and tasks in order to be considered painfree with the Hughston VAS.

Subjects' subjective rating of their current activity level, preproblem activity level, and desired activity level were not found to change over time or differ between the groups. This may have occurred due to the broad description of abilities within each category, and the fact that very few subjects rated their current activity level to be different than their activity level prior to the onset of their knee symptoms. This may indicate that the individuals in this study did not perceive their knee symptoms as limiting their overall functional ability.

Subjective pain response was further assessed during the performance of a functional movement. Both the exercise and exercise plus tape groups improved in their ability to perform a more difficult functional activity without pain. However, the exercise plus tape group was able to do so sooner (by week 4). The use of patellar taping appears to have accelerated the benefits of performing exercise alone. This supports the use of patellar taping[7,16] to decrease pain, which according to Antich and Brewster[21] should allow for more productive and beneficial quadriceps femoris strengthening.

The ability to reliably determine patellar alignment has been reported to be poor.[22] However, in a pilot study by this author, the intrarater reliability of the tester used in this study was found to be excellent (kappa coefficient = .78) according to criteria proposed by Landis and Koch.[23] This is consistent with the general assumption that techniques that rely on palpation or visual inspection tend to have poor interrater reliability, but a higher intrarater reliability. Therefore, since all evaluations and reevaluations were done by the same tester, the reliability of the technique used to assess patellar alignment in this study should be less of a concern.

Patellar orientation between the groups in the current study was not found to be different or to change over time. Whether patellar orientation should be expected to change was not identified by McConnell.[7,16,17] The findings of this study, no change in patellar orientation over time or between the groups, are consistent with those found by Bockrath et al.[13] Bockrath et al.[13] reported no change in PF congruency or patella rotation following PF taping despite a significant reduction in subjective reporting of pain during a 0.2 meter step down pretaping and posttaping. Therefore, if patellar taping does not change the immediate position of the patella, the practice of taping the patella to improve patellar position, and therefore increase VMO recruitment[7,16] may need to be more fully assessed.

In contrast, Doucette and Goble[1] did report a decrease in the congruence angle of the patella, as measured by a static Merchant's view x-ray, in a group of individuals who reported no pain after conservative treatment. This decrease in congruence angle was noted to position the patella in more of a medial tilt, and was assumed to decrease lateral patellar tracking. The findings of their study suggested that changes did occur in patellar alignment as a result of conservative treatment. This raises the concern that the technique used to assess potential change in patellar position may need to be more specific than patellar orientation as assessed by palpation.

Electromyography of the QF in PFPS continues to be an area with much controversy. The two components examined in the present study were VMO:VL ratio and VMO and VL recruitment. Some studies have reported deficits in VMO relative to VL EMG activity (VMO:VL ratio) in symptomatic individuals,[14,24,25] while other studies have reported no difference between symptomatic and asymptomatic individuals.[19,26,27] Despite this controversy, most physical therapy interventions in the treatment of PFPS are directed at selectively enhancing VMO recruitment and strengthening. The use of patellar taping was recommended by McConnell[16] for these same reasons. McConnell[16] reported that appropriate taping of the patella increased ($p = .01$) the VMO:VL ratio during performance of an isometric contraction as compared to performance with the patella not taped. Cerny,[28] however did not find a difference in VMO:VL ratio while performing a number of exercises in both nonweight bearing and in weight bearing. He further reported that patellar taping had no affect on VMO:VL ratio despite a significant decrease in subjective reporting of pain. Similarly, in a training study by Willett and Karst,[29] no change was found in the magnitude of the VMO:VL contraction despite a significant reduction in pain following conservative treatment.

Another aspect of EMG activity that has been studied is the onset timing pattern, or motor control, of the VMO and VL. McConnell[7,16,17] identified the importance of strengthening the QF with emphasis on the quality of the contraction rather than the quantity of contractions. The quality component was described as the VMO firing before VL based on the findings of Voight and Wieder.[10] Voight and Wieder[10] found the VMO fired significantly faster than the VL in asymptomatic subjects and fired more slowly than the VL in symptomatic patients. In a more recent study by Karst and Willett,[30] no difference was found in onset timing pattern in a variety of exercises and positions, between symptomatic and asymptomatic individuals. Willett and Karst,[29] in a study of conservative treatment for PFPS, found no difference in onset timing of VMO and VL after 4 weeks of treatment.

The EMG results for onset timing in the present study are consistent with those reported by Voight and Wieder[10] who proposed that as subjects became painfree, they improved the onset timing of the VMO allowing the VMO to fire first relative to the VL.

Conclusions

The current study was designed to investigate whether there was a difference between the use of exercise and exercise plus patellar taping in the conservative management of individuals with PFPS. The results of this study indicate that subjects responded differently to the different treatments. Subjects in the exercise plus taping group reported a significant decrease in subjective symptoms and progressed to painfree functional activities more quickly than subjects who used exercise alone, or those who received no treatment. The mechanism by which taping helped, and pain relief occurred was not clear. While patellar taping appeared to be related to improved onset timing of the VMO before the VL, it did not appear to be related to changes in patellar orientation, or VMO:VL ratio. The positive effect of taping may be related to additional sensory input into the PF joint area or a placebo effect. Further studies using patellar taping techniques, in order to better assess the mechanism of benefit, appears appropriate.

Clinical Implications

Quadriceps strengthening, as a component of conservative management of individuals with PFPS, would appear to be facilitated by the use of patellar taping. In those individuals with a significant amount of pain, use of patellar taping to decrease pain complaints during rehabilitation may be appropriate. Also, in those individuals where a quick response is necessary, taping may facilitate the speed at which improvement occurs. However, the risks of taping, skin allergies, and skin breakdown, as well as the added cost of the taping supplies, must be weighed against the benefits of a faster recovery. Clinicians need to consider all of these factors when deciding whether to include patellar taping into the conservative management approach.

REFERENCES

1. Doucette SA, Goble EM. The effect of exercise on patellar tracking in lateral patellar compression syndrome. *Am J Sports Med.* 1992;20:434-440.

2. Landry GL. Patellofemoral stress syndrome: a common but complex problem. *Compr Ther.* 1988;14:21-28.

3. Buchbinder MR, Napora NJ, Biggs EW. The relationship of abnormal pronation to chondromalacia of the patella in distance runners. *J Am Podiatr Assoc.* 1979;69:159-162.

4. Carson WG, James SL, Larson RL, et al. Patellofemoral disorders: physical and radiographic evaluation. *Clin Orthop.* 1984;185:165-177.

5. Magee DJ. *Orthopedic Physical Assessment.* 2nd ed. Philadelphia: WB Saunders;1992:372-374.

6. Insall J. "Chondromalacia patellae": patellar malalignment syndrome. *Orthop Clin North Am.* 1979;10:117-127.

7. McConnell J. The management of chondromalacia patellae: a long-term solution. *Australian Journal of Physiotherapy.* 1986;32:215-223.

8. McConnell J. *The advanced McConnell patellofemoral treatment plan.* 1992;Course material. Jenny McConnell, BAppSci(Phty), GradDipManTher, MBiomedEng, PO Box 425, Neutral Bay, New South Wales, Australia.

9. Shangold MM, Mirkin G. *Women and Exercise Physiology and Sports Medicine.* Philadelphia: FA Davis;1988:201-209.

10. Voight ML, Wieder DL. Comparative reflex response times of vastus medialis obliquus and vastus lateralis in normal subjects and subjects with extensor mechanism dysfunction: an electromyographic study. *Am J Sports Med.* 1991;19:131-137.

11. Beck JL, Wildermuth BP. The female athlete's knee. *Clin Sports Med.* 1985;4:345-366.

12. Sommer HM. Patellar chondropathy and apicitis, and muscle imbalances of the lower extremities in competitive sports. *Sports Med.* 1899;5:286-394.

13. Bockrath K, Wooden C, Worrell T, et al.. Effects of patella taping on patella position and perceived pain. *Med Sci Sports Exerc.* 1993;25:989-992.

14. Wise HH, Fiebert IM, Kates JL. EMG biofeedback as treatment for patellofemoral pain syndrome. *J Orthop Sports Phys Ther.* 1984;6:95-103.

15. Ingersoll CD, Knight KL. Patellar location changes following EMG biofeedback or progressive resistive exercises. *Med Sci Sports Exerc.* 1991;23:1122-1127.

16. McConnell J. Training the vastus medialis oblique in the management of patellofemoral pain. *Proceedings of the 10th International Congress of the World Confederation for Physical Therapy; Sydney, New South Wales, Australia;* 1987.

17. McConnell J. Patella alignment and quadriceps strength. From the Proceedings of the MTAA conference;November 1987. Jenny McConnell, BAppSci(Phty), GradDipManTher, MBiomedEng, PO Box 425, Neutral Bay, New South Wales, Australia.

18. Flandry R, Hunt JP, Terry GC, Hughston JC. Analysis of subjective knee complaints using visual analog scales. *Am J Sports Med.* 1991;19:112-118.

19. Boucher JP, King MA, Lefebvre R, Pepin A. Quadriceps femoris muscle activity in patellofemoral pain syndrome. *Am J Sports Med.* 1992;20:527-532.

20. Spencer JD, Hayes KC, Alexander IJ. Knee joint effusion and quadriceps reflex inhibition in man. *Arch Phys Med Rehabil.* 1984;65:171-177.

21. Antich TJ, Brewster CE. Modification of quadriceps femoris muscle exercises during knee rehabilitation. *Phys Ther.* 1986;66:1246-1250.

22. Fitzgerald GK, McClure PW. Reliability of measurements obtained with four tests for patellofemoral alignment. *Phys Ther.* 1995;75:84-90.

23. Landis RJ, Koch GG. Cited by: Fitzgerald GK, McClure PW. Reliability of measurements obtained with four tests for patellofemoral alignment. *Phys Ther.* 1995;75:84-90.

24. Mariani PP, Caruso I. An electromyographic investigation of subluxation of the patella. *J Bone Joint Surg Am.* 1979;61-B:169-171.

25. Souza DR, Gross MT. Comparison of vastus medialis obliquus: vastus lateralis muscle integrated electromyographic ratios between healthy subjects and patients with patellofemoral pain. *Phys Ther.* 1991;71:310-317.

26. Reynolds L, Levin TA, Medeiros JM, et al. EMG activity of the vastus medialis oblique and the vastus lateralis in their role in patellar alignment. *Am J Phys Med Rehabil.* 1983;62:61-70.

27. Soderberg GL, Minor SD, Arnold K, et al. Electromyographic analysis of knee exercises in healthy subjects and in patients with knee pathologies. *Phys Ther.* 1987;67:1691-1696.

28. Cerny K. Vastus medialis oblique/vastus lateralis muscle activity ratios for selected exercises in persons with and without patellofemoral pain syndrome. *Phys Ther.* 1995;75:672-683.

29. Willett GM, Karst GM. Patellofemoral disorders: is timing or magnitude of vastus medialis obliquus and vastus lateralis muscle activity affected by conservative treatment? Presented at 1995 American Physical Therapy Association Combined Sections Meeting; February 1995; Reno, NV.

30. Karst GM, Willett GM. Onset timing of electromyographic activity in the vastus medialis oblique and vastus lateralis muscles in subjects with and without patellofemoral pain syndrome. *Phys Ther.* 1995;10:117-127.

APPENDIX A

INFORMED CONSENT FORM

Informed Consent Form

Title: Effects of exercise and taping in females with patellofemoral pain.

Principal Investigator: Lori Froehling

The principal investigator will review the following with each subject.

You will be evaluated by a physical therapist who is trained and experienced in the evaluation of knee pain. The evaluation will take approximately thirty minutes, and will consist of the following: movement testing to assess muscle flexibility, palpation of the patella to assess patella position, surface electromyography (EMG) to assess muscle strength and recruitment of the two portions of the quadriceps, and identification of a functional activity (walk, squat, steps) which reproduces your symptoms.

You will then be randomly assigned to one of three groups: exercise, exercise combined with patellofemoral taping, and control. Subjects in groups one and two will be instructed in a home exercise program to be performed daily which will take approximately fifteen minutes. Subjects in group two will also be instructed in appropriate taping techniques to use daily for one to four weeks. Application of the tape will take approximately ten minutes.

You will need to come in for fifteen minutes to review and progress exercises during weeks two and six. During week four you will also need to come in for thirty minutes to be reevaluated and to fill out the questionnaire on the behavior of your symptoms.

Subjects in groups one and two will be provided with written exercise instructions and subjects in group two will be provided with the necessary taping supplies at no cost.

Potential risks of participation include general muscle soreness in the legs from stretching and strengthening exercises. Subjects in group two may experience skin irritation from use of tape.

Potential benefits include a free physical therapy evaluation and exercise instruction, a better understanding of knee function, and potentially a decrease in knee pain.

At the end of the study, subjects in all groups will be instructed in exercises and/or taping as appropriate.

(OVER)

The principal investigator will answer any and all inquiries concerning the procedures, risks and benefits.

1. I, ______________________, being of sound mind and _____ years of age
(Signature of Subject)
do hereby consent to, authorize and request the principal investigator (and co-workers, agents, and employees) to perform on me the proposed procedure, treatment, research, or investigation (herein called "Procedure").

2. I have read the above document, and I have been fully advised of the nature of the Procedure and the possible risks and complications involved in it, all all of which risks and complications I hereby assume voluntarily.

3. I hereby acknowledge that no representations, warranties, guarantees, or assurances of any kind pertaining to the Procedure have been make to me by the University of Wisconsin-La Crosse, the officers, administration, employees, or by anyone acting on behalf of any of them.

4. I understand that I may withdraw from the program at any time.

Signed at _______________ this _____ day of _____, 1995, in the presence of the witness whose signature appears below opposite my signature.

WITNESSED BY:

______________________________ ______________________________

Subject's Signature Date Signature Date

APPENDIX B

PATELLOFEMORAL PAIN EVALUATION FORM

PATELLOFEMORAL PAIN EVALUATION FORM

Name________________ Involved knee________
Date_________________ Group______________

Hughston Initial Knee History_______ Functional Activity Level________

STANDING ALIGNMENT:
Q-angle R_____ L_____
Genu-recurvatum R + - L + -
Neutral calcaneal stance R_____ L_____

FUNCTIONAL INDICATOR: no (0) yes (1)
symptom with: Walk _____ _____
double leg squat _____ _____
single leg squat _____ _____
step up _____ _____
step down _____ _____

SITTING ASSESSMENT:
ROM: R_____ L_____
Patellar tracking: Medial R L Neutral R L Lateral R L

SUPINE ASSESSMENT:
Quadriceps Atrophy R_____cm L_____cm
Hamstring flexibility R_____ L_____
Hip flexor/quad flexibility: Thigh to table R_____ L_____
Knee flexion R_____ L_____

PATELLAR ORIENTATION:

Components:	R static	R dynamic	L static	L dynamic
Glide	0 1	+ Ø	0 1	+ Ø
Lateral tilt	0 1 2	+ Ø	0 1 2	+ Ø
Anterior-Posterior tilt	0 1 2	+ Ø	0 1 2	+ Ø
Patellar alignment score:	R__________		L__________	
Rotation	-1 0 1		-1 0 1	

SIDELYING ASSESSMENT:

	Normal	Restricted
Lateral retinaculum	R L	R L
Iliotibial band flexibility	R_____cm	L_____cm
Gluteus medius strength	R_____lbs	L_____lbs

PRONE ASSESSMENT:

Gastrocnemius flexibility	R_____	L_____
Soleus flexibility	R_____	L_____
Gluteus maximus strength	R_____lbs	L_____lbs

EMG ASSESSMENT:

	R	L
Quad set - supine: firing pattern	VMO first VMO second VMO:VL same	VMO first VMO second VMO:VL same
VMO:VL ratio	__________	__________
Active knee extension - sitting: firing pattern	VMO first VMO second VMO:VL same	VMO first VMO second VMO:VL same
VMO:VL ratio	__________	__________

APPENDIX C

EXERCISE PROGRAM FOR PATELLOFEMORAL PAIN SYNDROME

EXERCISE PROGRAM FOR PATELLOFEMORAL PAIN SYNDROME

Subjects will be instructed in an individualized program of exercise based on deficits found during the physical examination. Exercise programs will be progressed based on individual progress. Exercise programs will consist of exercises taken from the following categories.

A. Instruction in proper lower extremity mechanics during functional activities such as walking and squatting. Subjects will be instructed to avoid hyperextension of the knee, or excessive flexion in order to avoid excessive patellofemoral compression forces.

B. VMO re-education/strengthening exercises to consist of a progression of exercises with emphasis on VMO recruitment. Exercises will progress from open chain to closed chain Exercises to include the following: quadriceps sets in slight flexion and in multiple angles; step stance and step through; small knee bends; wall sit; step up; step down; and lateral step up.

C. Quadriceps strengthening and general lower extremity strengthening to include the following: short arc quad strengthening; straight leg raise for flexion, abduction, adduction and extension; single and double heel raise.

D. General lower extremity flexibility exercises to include the following: iliopsoas stretch; quadriceps stretch; hamstring stretch; iliotibial band stretch; gastrocnemius stretch; and soleus stretch.

E. Lateral Retinaculum stretches using the following techniques: soft tissue massage; patellar tilt; and patellar medial glide.

APPENDIX D

PATELLAR TAPING SHEETS

Name____________________

Taping Information

PURPOSE:

1) To passively stretch the tight lateral structures;
2) To realign the patella to facilitate vastus medialis obliquus (VMO) recruitment and strengthening;
3) Decrease pain, swelling and VMO inhibition.

GUIDELINES:

1) The tape should be <u>worn every day for two weeks</u>.
2) Remove the tape at night and clean the skin well. It is very important to protect the skin and give it time to rest.
3) Skin care is very important. See handout on skin care for patellofemoral taping.
4) You may need to tighten the tape after a couple of hours as it does loosen. The tape will loosen more quickly if you are very active or if moving into extreme amounts of knee flexion.
5) If you have pain with the tape on, re-adjust the tape.
6) If activity is painful, even with tape, do not continue it.
7) You should never train/exercise with or through pain or effusion.

TAPING:

Faulty patellar (knee cap) alignment can be in one or more of four components: glide, tile, rotation, and anteroposterior.

1) You will tape according to what was specifically found in the evaluation of your knee.
2) The following is a list of the four components. The components that you need to tape for are checked.

   ______glide
   ______tilt
   ______rotation
   ______anteroposterior

3) Please refer to the attached pages for taping techniques.
4) If you have any questions about taping, please contact me as soon as possible.

SKIN CARE FOR PATELLOFEMORAL TAPING

1. Friction rub - this is a relatively common problem. It occurs on the inside area of the knee where the skin is softer and is similar to heat rash. It is due to the friction of the tape against the skin as the tape slowly looses it's hold. We can minimize this problem by doing the following:

   a. Lift the tissues on the inside of the knee towards the knee cap as you secure the tape, this results in creases of the skin in the inside of the knee.

   b. Remove the tape properly. Peel the tape <u>slowly</u> back over on itself while pushing the skin in the opposite direction. Do not be tempted to pull the tape off fast. You may use baby oil or tape adhesive remover at the edge of the tape to facilitate removal.

   c. Good skin preparation is important, keep the skin shaved, although try not to shave just prior to taping.

   d. Use rubbing alcohol on the skin after the tape is removed to help toughen the skin. This is a preventive measure to be done before the skin breaks down.

   e. Once the skin has broken down it is less likely to break down again. It is similar to developing a callous. If the skin does break down, use protective pads or band aids under the white tape. The tape will not be as firm but <u>do not tape on an area of broken skin</u>. **If you get any skin break down, contact me as soon as possible.

   f. Once the tape is removed, nourish the skin with moisturizer at night. Wash the moisturizer off before applying tape the next day. NEVER WEAR YOUR TAPE AT NIGHT, UNLESS DIRECTED.

2. Allergic Reaction - a small percentage of people who are taped may experience an allergic reaction if they have not been exposed to the zinc oxide adhesive before. This is an ingredient in the brown tape. The whole knee area will come up in welts and be incredibly itchy. Treat an allergic reaction in the following way:
   a. If you develop an allergic reaction, discontinue taping and contact me as soon as possible.
   b. Cortisone cream on the area may help settle the rash quickly.
   c. Ice may help calm the itch.

Weaning Off The Tape

How do you wean off the tape?

Start by taping every other day for one week. Progress to taping every third day, etc. Continue to wear the tape for activities that are more aggressive such as sports, etc.

When are you ready to leave the tape off for all activities of daily living?

When you are able to sustain a good muscle contraction of the VMO while wearing the tape during 2 cycles of the following test:

a. sustain a quarter squat for one minute against a wall.
b. sustain a half squat for one minute against a wall
c. perform 5 sets of 10 step downs with good control and alignment.
d. walk for 5 minutes with active VM) contraction.

When are you ready to leave the tape off for more aggressive activities such as sports, etc.?

About a month after weaning off the tape for activities of daily living, repeat the above test without tape and add climbing the stairs for 5 minutes. Watch for proper knee alignment, and good VMO contraction.

McConnell, J. *The advanced McConnell patellofemoral treatment plan.* 1992 Course Manual.

APPENDIX E

REVIEW OF RELATED LITERATURE

REVIEW OF RELATED LITERATURE

Factors that influence patellofemoral pain syndrome (PFPS) and their treatment are quite complex, therefore, these factors will be addressed as follows: the biomechanics of the lower extremity and it's influence on lower limb function, primarily the patellofemoral (PF) joint; surface electromyography (EMG) of the quadriceps muscle, and it's influence on knee function; various evaluation techniques of patients with PFPS ranging from clinical to invasive; and the treatment of PFPS with techniques ranging from conservative/ nonoperative to operative.

Anatomy and Kinematics that Influence Knee Function

The knee is a complicated area to evaluate due to the significance of the knee ligaments and muscles and their role in knee stability. Also, the importance of the lumbar spine, hip, and ankle and their influence on knee joint function and ability to refer pain to the knee must be considered. Williams[1] stated that changes in the foot are the result of pathology in the proximal links of the kinematic chain. On the contrary, Ramig et al[2] commented that foot pathology causes more proximal deformity. While neither extreme is probably correct, Rusche and Mangine[3] divided the factors that influence the knee into two categories: intrinsic and extrinsic factors. Intrinsic factors included structures of the knee while extrinsic factors involved biomechanical problems of the hip or foot. The lumbar spine would also be considered an extrinsic facto·

Each of these factors, foot, hip, lumbar spine, and knee will be considered as they influence PFPS. In addition the neuromuscular control of the lower limb will also be considered as a factor influencing PFPS.

Foot/Ankle

The kinematics and kinetics of the ankle and foot during gait are well documented. The ankle has commonly been called the mobile adaptor as it accepts, absorbs, and transfers forces through the foot in gait. The foot makes contact with the floor in a supinated position. As weight is transferred over the foot it pronates until the forefoot is supported on the floor at approximately midstance. As the foot pronates, the hip and leg are also internally rotating. As weight is transferred to the forefoot and through toe off, the foot again supinates and the hip and leg now move into external rotation.[1,2,4]

Buchbinder et al[4] proposed that if prolonged pronation occurred in the stance phase, the leg and pelvis would continue to internally rotate when they should be rotating externally. The resultant internally rotated position could cause abnormal quadriceps pull due to both the origin and insertion of the quadriceps being lateral to the patella. Quadriceps contraction would now pull the patella in a lateral direction causing it to glide over the lateral condyle of the femur instead of riding between the femoral condyles. The result would be faulty patellar alignment which could lead to PFPS.

Powers et al[5] assessed the rearfoot position in patients diagnosed with PFPS and in the normal population. The PFPS group had a small but significantly ($p = .0002$) greater rearfoot varus compared to the normal group. These results were felt to support the functional relationship between rearfoot position and patellofemoral pain and may implicate rearfoot varus as a predisposing factor to PFPS.

When abnormal pronation is identified as the cause of the knee pain, correction with the use of the functional orthotics is thought to be ideal.[4] A study by Eng and Pierrynowski[6] found that use of a soft temporary custom made orthotic to correct excessive forefoot varus or calcaneal valgus enhanced the traditional exercise treatment for PFPS.

Knee

The knee joint is comprised of the tibiofemoral joint and the patellofemoral joint. The tibiofemoral joint is a modified hinge joint with extensive synovium and capsule which communicates with many of the bursae and pouches around the knee joint and is continuous with the patellofemoral joint capsule. Stability of the tibiofemoral joint is from the ligaments and muscles that attach in and around the knee.[7] It is beyond the scope of this paper to detail this component of the knee.

Normal knee joint range of motion (ROM) has been cited in many sources. Full knee extension is cited as 0 degrees, with full flexion ranging from 130 - 150 degrees.[8,9] Hoppenfeld[10] cited 0 - 135 degrees as normal knee range of motion.

The patellofemoral joint is a modified plane joint. The articular surface of the patella has the thickest layer of cartilage in the body.[7] As the knee moves from flexion to extension, the articular surface of the patella changes its contact with the medial and lateral femoral condyles. The lateral femoral condyle projects an estimated 7 mm more anteriorly than the medial femoral condyle. This is thought to assist in preventing lateral displacement of the patella.[3] The lateral articular surface of the patella is also wider. The articular surface of the patella is said to have five facets: superior, inferior, lateral, medial, and odd.[7] See Figure A1.

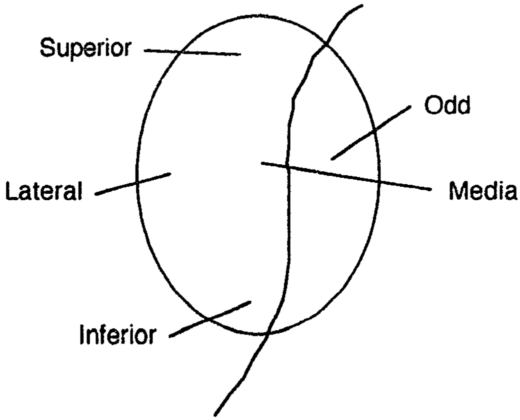

Figure A1. Posterior surface of patella with facets labeled.

A number of studies have looked at patellofemoral contact areas and forces in cadaver knees, as they moved through flexion and extension, with similar findings. In full extension, little or no contact between the patellar and femoral articular surfaces was found.[11] As the knee moved into 20 degrees of flexion the distal portion of the patella makes initial contact with the articular surface of the femur. Contact on the posterior surface of the patella moves from distal to proximal as knee flexion occurs. Ficat and Hungerford[11] found that the patella reached its most proximal position by 90 degrees of flexion while Huberti and Hayes[12] found this to occur at 120 degrees of flexion.

Studies by Goodfellow et al[13] Ficat and Hungerford,[11] and Huberti and Hayes,[12] found that in cadaver knees from 20 degrees to 90 degrees the entire articular surface of the patella, except the odd facet was in contact with the femoral articular surface. As flexion increased, the area in contact also increased,[11] with maximum contact area at 120 degrees of flexion.[12]

Contact of the odd facet with the medial femoral condyle occurred once flexion reached about 135 degrees.[7,11,13] Surface degeneration on the odd facet is often blamed for PFPS. However, most daily activities can be performed with the first 120 degrees of knee flexion, thereby not overusing the cartilage on the odd facet. Rather the degenerative changes may be a result of disuse.[13]

Huberti and Hayes[12] found patellofemoral contact pressure to be greatest at 60 degrees and 90 degrees of flexion in cadaver knees. Mathematical calculations of the forces applied to the knee joint in various degrees of flexion will also produce patellofemoral joint reaction (PFJR) forces. Reilly and Martens[14] calculated the PFJR force for level walking to be 0.5 times body weight. PFJR force when stair climbing and descending was found to be 3.3 times body weight. Magee[7] stated that the PFJR force while perfoming a squat would be seven times body weight.

As the patella glides through the femoral condyles during knee flexion and extension, it performs many functions. Most sources agree that the patella's primary function is to increase the efficiency of extension. The patella does this through increasing the distance of the extensor apparatus from the axis of flexion and extension of the knee. Magee[7] noted that this occurred primarily in the last 30 degrees of extension. This lengthening of the lever arm also decreased the patellofemoral compression forces.[15] The patella also functions to decrease the friction of the quadriceps mechanism as it passes over the femoral condyles. The patella acts as a guide for the quadriceps muscle through the quadriceps tendon, controls capsular tension in the knee, and protects the cartilage of the femoral condyles by functioning as a bony shield. Finally, and least of all, the patella improves the aesthetic appearance of the knee.[11]

The ability of the patella to function normally in the extensor mechanism can be influenced by a number of factors. The quadriceps femoral angle (Q angle) has been shown to influence the extensor mechanism, and has been associated with patellofemoral problems.[7] The Q angle is measured as the angle between a line from the midpoint of the patella to the tibial tubercle and a line from the midpoint of the patella to the anterior superior iliac spine.[16]

The values cited for normal Q angles are quite varied in the literature. The American Orthopaedic Association[17] considers 10 degrees to be normal and 15 to 20 degrees to be abnormal, with no differentiation made for males and females. Many studies have shown that the Q angle is larger for females than males. Hsu et al[18] and Woodland and Francis[19] found that the mean Q angle in females was significantly ($p < .001$) larger than in males. Horton and Hall[20] found that the Q angle for females was 4.6 degrees higher than that for males. The values most commonly cited in the literature were 15 degrees for males and 20 degrees for females, with values larger than this considered abnormal.[3,20]

Schulthies et al[21] evaluated the validity of measured Q angle compared to the average resultant force of the QF in male cadavers. They found a significant relationship ($r = .919$) between the two measurements. However, the average QF resultant force was significantly ($p = .0003$) greater than the measured Q angle. Therefore, the authors concluded that measured Q angle may underestimate the actual lateral force of the QF on the patella.

The position in which the Q angle is measured has been studied with somewhat conflicting results. Woodland and Francis[19] found the Q angle measured in standing to be increased 0.9 degrees for males and 1.2 degrees for females when compared to the supine position. Although the difference was small, it was significant ($p < .001$) due to the large sample size (269 males and 257 females). Guerra et al[22] using a much smaller sample (30 males and 30 females) found no difference between the supine and standing positions.

Guerra et al[22] also measured the effect of pelvic width (distance between anterior superior iliac spines) and quadriceps contraction on Q angle in both the standing and supine position. They found that pelvic width was significantly ($p < .001$) greater in standing versus supine with males pelvic width found to be larger than females. Quadriceps contraction compared to the relaxed condition was found to significantly ($p < .001$) alter Q angle, in both the supine and standing position, with no difference found between males and females.

Hsu et al[18] found a difference in knee joint obliquity angle in males and females. They found a significant ($p < .05$) difference in that males had a medial tilt (varus) while the females had a lateral tilt (valgus). They also found that maximum pressure on the tibial plateau was significantly ($p < .05$) greater for females than males.

Insall et al[23] found that lateral tracking of the patella due to an increased Q angle caused abnormal sheer stress on the cartilage and increased the loading pressure. Huberti and Hayes[12] found that both increases and decreases in the normal Q angle increased peak patellofemoral pressures and changed the normal cartilage wear pattern. Due to the fact that many factors appear to influence Q angle, and faulty Q angle may be related to PFPS, using a standardized technique to measure Q angle would appear to be vital.

Flexibility and strength of the lower extremity and trunk must also be considered. Flexibility of hip rotation and spine extension as well as specific assessment of the gastroc-soleus group, hamstrings, iliotibial band, rectus femoris, and iliopsoas should be made.[24] Tightness in the hamstring group increased the work load of the quadriceps and would inhibit the quadriceps due to reflex inhibition.[25] Iliotibial band tightness has been linked to knee pain and chondromalacia of the patella due to it's lateral pull on the patella.[26] Winslow, and Yoder[27] found an association between ITB tightness and PFPS in ballet dancers ($p < .01$).

Strength measurement should assess the posterior tibialis, quadriceps with special emphasis on the VMO and VMO recruitment, gluteus medius, and iliopsoas.[24] A study by Sommer[28] found that despite subjects having well trained VMO, other muscle imbalances of leg or trunk flexibility and strength prevented normal knee alignment in jumping activities. Sommer[28] noted that movement of the femur toward midline of the body in jumping activities was due to a shortened iliopsoas muscle (or shortened in fatigue with relative or absolute weakened gluteal, hamstring, and rectus abdominus muscles). These subjects were found to have well trained and strong vastus medialis obliquous (VMO) muscles due to functioning to counteract the valgus strain at the knee. Therefore, despite strong VMO musculature, other muscle imbalances of the trunk and lower extremity prevented normal knee alignment in jumping and may result in symptoms related to PFPS.

<u>Kinematics of Lower Extremity Function</u>

The function of the lower extremity as a whole and the influence of neuromuscular control in gait was studied by Radin et al.[29] Eighteen subjects with knee pain and 14 subjects without knee pain were evaluated. Parameters that were studied were electromyography of the quadriceps and hamstrings, acceleration of the thigh and shank, and ground reaction forces at heel strike. The study found what they termed "microklutziness", a "micro-incoordination" of neuromuscular control that is not visible to the naked eye. Radin et al[29] found the knee pain group to have a higher ground reaction force, a faster downward velocity of the ankle moving into plantarflexion, and a larger angular velocity of the shank pushing the knee into hyperextension. Follow through was characterized by larger peak axial and angular accelerations of the leg. The knee pain group also had decreased maximum knee flexion during stance and a shorter period of eccentric quadriceps firing, indicating decreases in shock absorption ability. The authors concluded that such a sequence of events represented impulse loading which has previously been shown to cause osteoarthrosis in animal studies.

Surface Electromyography of the Extensor Mechanism

As stated in the previous section, there are many factors that influence knee joint function and patellofemoral alignment. The function of the quadriceps femoris as it performs knee extension has been studied extensively. The role of each of the four heads of the quadriceps femoris; rectus femoris (RF), vastus lateralis (VL), vastus intermedius (VI), and vastus medialis (VM), has also been studied. Basmajian et al[30] using wire electrodes, found all portions of the quadriceps to be active throughout the range of 90 to 180 degrees and flexion back to 90 degrees when performing unloaded knee extension. This is contrary to previous statements that the VM is active only in terminal extension, and therefore must be the most important portion for performing end range extension. Basmajian and Deluca[31] pointed out, however, that due to the direction and insertion of the lower fibers of the VM, the real function of the VM at the end of extension must be to prevent lateral dislocation of the patella. This interpretation is consistent with findings by Lieb and Perry.[32]

In a study by Mariani and Caruso[33] the function of the VM and VL in painfree subjects was compared to subjects with subluxation of the patella. Both the VM and VL had increased EMG activity from 30 degrees of flexion to full extension in painfree subjects. The painfree subjects were also found to have slightly increased VL activity from 90 to 30 degrees. In subjects with subluxation of the patella, the activity of the VM was decreased considerably throughout the range but especially between 30 degrees and full extension. Evaluation of the uninvolved knee also revealed decreased VM activity throughout the range of motion. These authors concluded that the presence of similar EMG changes in the uninvolved knee was indicative of factors that predisposed the subject to subluxation of the patella versus true muscular atrophy.

These same subjects with subluxation of the patella, then underwent Elmslie-Trillat realignment surgery. The VL and VM EMG activity was retested 6 to 12 months later. Mariani and Caruso[33] found that VM activity had improved to a level similar to the VL. These findings support the important relationship between the VM and malalignment of the extensor mechanism.

An imbalance in the activity of the VM and VL has often been cited as a reason for lateral tracking of the patella. Most studies use a ratio of vastus medialis obliquus (VMO) to VL when assessing potential muscle imbalance.

Reynolds et al[34] found low levels of EMG activity in both the VMO and VL in a study of healthy females performing the last thirty degrees of knee extension in weight bearing. They also found no difference in VMO and VL EMG activity and noted this to be due to the opposing forces they provide in dynamic patellar stability.

In a study by Souza and Gross,[35] VMO:VL EMG ratios of healthy subjects were compared to patients with PFPS. Patients performed maximal and submaximal isometric contractions at 10 degrees of knee flexion and then performed concentric and eccentric muscle contractions be ascending and descending stairs. The results indicated the VMO:VL ratio was significantly greater for healthy subjects than for PFPS subjects on both their involved and uninvolved knees. They also found a significant difference between the types of contraction with VMO:VL ratios great for concentric and eccentric conditions versus maximal and submaximal isometric contractions. The authors concluded that individuals with PFPS may have different quadriceps femoris activation patterns. Also, the use of concentric and eccentric strengthening may be appropriate for patients with PFPS.

Another study performed by Boucher et al[36] looked at VMO:VL ratios of maximal isometric contractions at 90 degrees, 30 degrees and 15 degrees of knee flexion in subjects with PFPS and asymptomatic subjects. No difference was found between subjects or between the three angles. However the VMO:VL ratio of the five PFPS subjects with the largest Q angles was found to be significantly ($p < .05$) smaller when compared to asymptomatic subjects. The ratio was also found to be smaller at 15 degrees than at 90 degrees. The authors suggested that PFPS is more likely due to mechanical disturbance (abnormal Q angle) which may lead to VMO atrophy as a secondary finding.

Assessment of the VMO:VL ratio has also been used to compare EMG activity of the quadriceps femoris muscle during exercise. In 1983, Soderberg and Cook[37] compared EMG activity of the VMO, RF, gluteus medius, and biceps femoris (BF) during maximally resisted straight leg raises (SLR) and quad setting (QS) in asymptomatic subjects. They found the VMO, BF and gluteus medius to be significantly more active during QS and the RF to be more active during the SLR exercises. Soderberg et al.[38] using the same methods looked at EMG activity of the quadriceps femoris in symptomatic and asymptomatic subjects. The results of the Soderberg et al.[38] study confirmed the findings of Soderberg and Cook.[37] Soderberg et al.[38] also found that combining a QS with the SLR produced significantly ($p < .05$) greater EMG activity than that produced by the QS or SLR alone.

Quadriceps femoris activity has also been found to be facilitated by other muscles. Hanten and Schulthies[39] studied the effect of hip adduction and internal tibial rotation on EMG activity of the VMO and VL. An increase in VMO activity when performing hip adduction exercises was anticipated due to the finding by Bose et al[40] who found the origin of the VMO to be from the tendons of the adductor magnus and longus. Hanten and Schulthies[39] found significantly higher VMO EMG activity compared to the VL when performing hip adduction. Medial tibial rotation was not found to effect the VMO or VL EMG activity.

Contrary to the above findings, Karst and Jewett,[41] reported that while QS was found to produce significantly ($p < .05$) more activity in the medial components of the RF than SLR, no difference was found between SLR, SLR with lateral rotation, or SLR with adduction.

Hodges and Richardson[42] studied the effect of three levels of hip adductor contraction on the VMO and VL in weight bearing (WB) and nonweight bearing (NWB). The VMO:VL ratio was found to be greater in WB than in NWB without hip adduction. When hip adduction was superimposed on quadriceps femoris contraction in WB, EMG activity of the VMO increased relatively more than the VL at each level of contraction. In the NWB position, VMO was found to increase only when maximal hip adduction contraction was performed. These authors pointed out that these findings are consistent with the functional role of the adductor magnus, in that it would be more active in conditions of high load or in WB. They concluded that therapeutic exercise designed to influence VMO:VL ratio should consider the influence of the adductor magnus on VMO recruitment and contraction.

In a more recent study, Cerny[43] looked at VMO:VL activity ratios during selected exercises in subjects with and without PFPS. The author looked at exercises performed in both NWB (open chain) and WB (closed chain). He reported that QS produced the greatest EMG activity for open chain exercises. One exercise, knee extension with medial rotation, produced a higher VMO:VL activity ratio than knee extension with lateral rotation. No other difference was found between any of the open or closed chain exercises in selectively enhancing VMO activity over that of the VL. Based on his findings, he questioned whether the VMO could be selectively trained to increase its activity.

Cerny[43] also found that subjects with and without PFPS had similar VMO:VL ratios during open chain exercises. However, subjects with PFPS had lower VMO:VL activity ratios in closed chain exercises than subjects without PFPS. While the author was uncertain about the statistical significance and importance of this finding, he recommended a need for further research in this area.

Reflex response times of the VMO and VL have also been studied in asymptomatic subjects and subjects with extensor mechanism dysfunction. A study in 1991 by Voight and Wieder[44] found the reflex response times to a patellar tendon tap were different in asymptomatic and symptomatic subjects. Asymptomatic subjects were found to have VMO firing significantly ($p < .001$) faster than the VL. However, in subjects with extensor mechanism dysfunction, the VL fired significantly ($p < .001$) faster than the VMO. Further comparison of firing times revealed no significant difference in firing times of the VMO between symptomatic and asymptomatic subjects. The firing times of the VL, however, were found to be significantly faster in the symptomatic subjects. The authors interpreted this increased VL reflex response time in subjects with extensor mechanism dysfunction to indicate a motor control problem versus inhibition of the VMO.

In 1985, Karst and Willett[45] did a study that looked at onset timing of EMG activity in the VMO and VL in subjects with and without PFPS. No difference ($p > .16$) was found between symptomatic and asymptomatic subjects in reflex activity of the VMO and VL elicited by a patellar tendon tap. These findings were contrary to those reported by Voight and Wieder[44] and may have resulted from methodology differences. These differences included a device to provide a standardized reflex tap versus a manual tap that was used in the Voight and Wieder[44] study. Also, Karst and Willett[45] used computerized data collection at a rate of 4,000 Hz, that allowed temporal resolution of 0.25 milliseconds for computer-aided, off-line determination of EMG onsets, versus the dual channel oscilloscope from which the VMO and VL latencies were visually determined in the Voight and Wieder[44] study.

Karst and Willett[45] further looked at relative timing onsets of the VMO and VL during voluntary activity in both nonweight bearing (NWB) and weight bearing (WB) positions. They reported that onset of the VMO tended to be faster during voluntary contraction than during reflex activity, however, no difference was found between the NWB ($p = .44$) and WB ($p = .28$) conditions.

The onset timing difference in symptomatic subjects, as measured in the Karst and Willett[45] study, ranged from 5 to 13 milliseconds. The authors questioned the availability of clinical biofeedback units capable of detecting such small differences, and the ability of he human sensory systems to interpret visual feedback provided on such a small difference.

Trauma and joint effusion have also been found to effect EMG activity of the QF. Spencer et al[46] studied the effect of knee joint effusion in producing quadriceps reflex inhibition. Spencer et al[46] introduced 0.9% physiologic saline into the intraarticular space of 10 asymptomatic subjects. Inhibition of the quadriceps muscles was assessed through recording the Hoffman (H) reflex from the VM, VL and RF. Saline was injected at 10 ml increments up to a total of 60 ml. All subjects showed a significant reduction in H-reflex amplitude following saline injection. The greatest inhibition was of the VM which was reduced to 55.7%. The RF was reduced to 69.1% and VL reduced to 65.3%. A positive linear relationship was found between volume of saline and amount of inhibition. The threshold for inhibition of each of the muscles was found to be different. Inhibition of the VM occurred at a much smaller effusion of 20 to 30 ml, versus the RF and VL in which inhibition occurred at 50 to 60 ml. When the saline induction was preceded by a lidocaine injection, no inhibiton was found which led the authors to conclude that inhibition of the quadriceps is mediated through intracapsular afferent receptors.

Evaluation of Patellofemoral Pain Syndrome

Visual Analogue Scales

Vague aching pain around or under the patella is usually the primary complaint of individuals with PFPS. A complete subjective evaluation is necessary to assess onset of symptoms and any known causes. Pain, a subjective finding, is often difficult to quantify. The visual analogue scale (VAS) is considered to be one of the best methods available for the estimation of the intensity of pain.[47] The VAS consists of a horizontal or vertical line (usually 10 mm) with extreme limits of a symptom at the end points (i.e., no pain, extreme pain).

Carlsson,[48] using three males with chronic pain of nonmalignant origin, found the validity of VAS to be somewhat unsatisfactory. When comparing absolute and comparative scales, the absolute scale was less sensitive to bias. Carlsson[48] also found that the patient's ability to fill out the VAS reliably was quite variable.

Also in 1983, Price et al[49] studied the use of VAS for sensory intensity and affective (unpleasant) magnitude of pain. Six noxious stimuli were applied to the forearms of both chronic pain and healthy subjects. The authors concluded that a VAS was a valid tool for the measurement of and or comparison between chronic pain and experimental thermal pain.

Visual analog scales can also be used to measure other subjective symptoms. Flandry et al[50] developed a questionnaire consisting of a series of

VASs to assist with the gathering of subjective knee complaints. The questionnaire consisted of 28 questions which the subjects answered themselves. The Hughston Sports Medicine Foundation, Inc. : Initial Knee History (Hughston VAS)[50] was then compared to three other established subjective evaluation methods. The other three subjective evaluation methods were the Noyes, Larson, and Lysholm. The results of the study found a statistically significant correlation between the Hughston VAS and the other three scales with the greatest association found with the Larson knee scale. The study also found that patients preferred the Hughston VAS over the other scales due to ease of use, least confusing, and best characterization of symptoms. Flandry et al[50] noted that the Hughston VAS could be converted to objective measures which allowed both the magnitude (severity) and the temporal nature (how often) of a chosen symptom to be justified. They felt that a scale with only the extremes of the experience noted, no numbers or qualities, decreased the bias found in other scales. The authors concluded that the Hughston VAS was valid, increased patient compliance, had a greater sensitivity of measurement, reduced bias, and had the advantage of graphic representation and numeric analysis. They offered the Hughston VAS for use in further research to provide a standardized method and improved objectivity in subjective data collection.

Physical Examination

Standing. Overall standing alignment should be assessed for lower extremity influences on PFPS.[51] Flat feet or excessive pronation should be assessed.[52] Carson et al[53] noted that tibia vara as well as neutral position of the subtalar joint should be considered when excessive pronation is found.

The knee should be assessed for genu recurvatum, genu varum, and genu valgum.[53] Squinting patella, when the knee caps face inward toward each other instead of facing forward may also be present and should be noted.[54] Both Carson et al[53] and Insall[54] noted this to be a result of excessive femoral anteversion. Insall[54] also noted external tibial torsion and increased Q-angle to be factors contributing to squinting patellae.

Lower extremity mechanics should also be assessed during gait. Carson et al[53] noted that an angle of gait greater than 10 degrees may be abnormal and could be a result of excessive femoral anteversion or retroversion or excessive tibial internal or external torsion. McConnell[55] also recommended an assessment of squatting and ascending and descending stairs to assess lower extremity movement patterns in functional activities that may influence patellofemoral pain.

Sitting. Sitting examination should be done with the knees flexed to 90 degrees and the legs hanging free.[53] Patellar position over the distal femur can be noted. At 90 degrees of flexion, the patella is normally seated deep in the femoral sulcus. A patella that remains prominent or points toward the ceiling may be a result of patella alta. Patella that are laterally tilted, "grasshopper-eye" patella, also indicates abnormal patellar tracking.[53]

An assessment of active range of motion and patellar tracking during movement should be done. Range of motion is rarely found to be restricted.[54] Normal patellar excursion has been found to be 5 to 7 cm.[53] The movement should be smooth without excessive medial or lateral shifting. A sudden medial shift as the knee moves into flexion may indicate a laterally positioned patella.[56] Crepitis during active range of motion may be felt, however the clinical significance of crepitis continues to be questioned.

Supine. Evaluation begins with measurement of the Q-angle, with values greater than 15 degrees in males and 20 degrees in females considered abnormal.[3,21] The extensor mechanism musculature should be examined with emphasis on the VMO.[52] Atrophy may be measured by taking a circumferential thigh measurement, 10 cm above the superior pole of the patella.[53]

Patellar orientation or position can be assessed next. If faulty positioning is found, appropriate taping techniques can be suggested for treatment. In 1986, McConnell[57] identified three components of patellar alignment - the glide, the tilt, and the rotation components. McConnell[55] later differentiated the tilt into two components, the lateral tilt and the anterior-posterior tilt. The glide component is an assessment of the amount of medial and lateral deviation of the patella in the frontal plane. Normal displacement should be no more than one half the width of the patella both medially and laterally.[53] McConnell[57,58] found that almost all symptomatic individuals needed more medial glide of the patella. Carson et al[53] stated that a decreased medial glide may be due to tightness of lateral structures. In the McConnell[55] grading system, the patella is assessed if it is equally positioned between the most prominent medial and lateral points on the distal femur. If the distance difference is less than 0.5 cm it is considered normal and is recorded as a grade 0, if greater than 0.5 cm it is a grade 1. Dynamic assessment is done by performing a passive medial glide. If the patella is able to be moved to neutral it is a grade 1 Ø, if unable 1+.

The tilt component is an assessment of the deep retinacular fibers. The examiner palpates the medial and lateral border of the patella and assesses if the same proportion of the sides and posterior surface of the patella can be felt.[55] If the whole lateral side and posterior surface of the patella is easily felt it is a grade 0, if all the lateral, but no posterior surface can be felt it is grade 1, and if only a portion of the lateral surface can be felt it is a grade 2. Dynamic assessment is done with an active quadriceps contraction. If the surface area that is able to be palpated stays the same it is a grade 1 Ø or 2 Ø. If less surface area is now able to be palpated it is a grade 1+ or 2+.[55] Passive depression of the medial facet is also an assessment of lateral tilt, where inability to passively depress the medial border would be an indication of lateral retinaculum tightness.[56]

McConnell[55] assesses the rotation component by evaluating if the long axis of the patella deviates from the long axis of the femur. This is determined by assessing the angle made by a line drawn horizontally through the medial and lateral poles of the patella and a line through the long axis of the femur. If this angle is between 85 and 95 degrees it is a grade 0. If it is greater than 95 degrees, the patella is said to be externally rotated and is a grade 1. If the angle is less than 85 degrees, the patella is said to be internally rotated and is a grade -1. There is no dynamic test component for rotation.[55]

Anterior-posterior tilt component is the newest component in the McConnell patellar alignment assessment. This component determines the extent to which the inferior pole tilts into the soft tissue structures in the inferior knee area. This is assessed by palpating the inferior pole. If the medial and lateral sides and posterior surface of the inferior pole can be palpated easily it is a grade 0. If only the sides and not the posterior surface can be palpated it is grade 1, and if only a portion of the sides can be palpated it is a grade 2. The dynamic assessment is done with a quadriceps contraction. If less of the sides or posterior surface is able to be palpated it is assigned a +, if it does not change it is assigned Ø.[55]

Fitzgerald and McClure[59] studied the interrater reliability of four tests for patellofemoral alignment, as proposed by McConnell.[57] Overall they found poor to fair reliability (kappa correlation coefficients ranged from .10 to .36) and questioned the validity of using these tests when determining when and how to apply PF taping techniques.

Shangold and Mirkin[52] noted that while individuals with PFPS may have patella which are positioned lateral or ride lateral in the patellar groove, they are usually found to have a negative apprehension test for subluxation. The patient may, however, have pain with active quadriceps contraction with the knee held at 30 degrees of flexion.[53] Patella inhibiton or pain may also be elicited by holding the patella in the trochlear grove against active quadriceps contraction thereby increasing patellofemoral forces.[52,53] Insall,[54] however, pointed out that the previous test produces many false positives which result because of synovial entrapment. Therefore, he recommends a modified test where pressure is placed on lateral patellar border. Force is applied to compress the patella into the femoral grove and displace it medially. Pain with this maneuver is indicative of patellar dysfunction.

General palpation of the knee should also be completed, as well as performance of the normal special tests for the knee to rule out meniscal or ligamentous pathology. Hamstring length,[52] leg length inequality and the amount of dorsiflexion should also be noted.[53]

Sidelying. Iliotibial band tightness should be assessed using the Ober test[10] with special emphasis placed on tightness of the distal fibers. Gluteus medius strength can also be assessed in sidelying using established techniques.[60]

Prone. Heel-forefoot alignment can again be screened. Hip internal and external range of motion can be assessed with the knee in 90 degrees of flexion. External rotation is usually slightly greater than internal rotation and both should be between 35 and 45 degrees.[10] Carson et al[53] noted that if internal rotation is greater than external rotation by more than 30 degrees, increased femoral anteversion may exist with a resultant increased Q-angle. Gluteus maximus strength and recruitment as well as trunk extensor strength should also be assessed.[28]

Diagnostic Tests

Shellock et al[61] used kinematic magnetic resonance (MR) imaging to assess patellar tracking. Multiple sequential images were obtained form 0 to 32 degrees of flexion. The results indicated good visualization of the patellofemoral joint with obvious differences seen between healthy subjects and one patient with known patellofemoral malalignment.

Brossmann et al.[62] compared MR imaging of healthy and symptomatic subjects as the knee moved either passively or actively from 0 degrees to 28 to 32 degrees of flexion. They found that patellar tracking differed between the healthy and symptomatic subjects. They also found that tracking differed when active versus passive movement was done. The authors concluded that for evaluation of patellar tracking, active quadriceps contraction was essential for diagnosis of patellar malalignments. They further stated that many of the malalignment deficits would have been overlooked with static examination techniques.

Arthroscopic determination of patellofemoral malalignment has also been used. Søjbjerg et al[63] found a difference as to the degree of flexion at which the patella gained contact with the femur. In subjects with a healthy patellofemoral joint, the lateral facet aligned at 20 degrees of knee flexion, the patellar ridge at 35 degrees and the medial facet at 50 degrees. Subjects with patellofemoral malalignment showed similar contact with the lateral facet. However, a significant ($p < .01$) difference was found in patellar contact on the patellar ridge and the medial facet. Contact with the patellar ridge was found to occur at 55 degrees and at the medial facet at 85 degrees in subjects with PF malalignment.

Carson et al[53] noted that the arthroscope can facilitate proper diagnosis, however, it may produce some paradoxes. For example, the presence of chondromalacia may be found in asymptomatic subjects and smooth articular surfaces found in symptomatic subjects. Carson et al[53] concluded that arthroscopic evaluation may facilitate proper diagnosis but is not a substitute for a comprehensive physical examination. They also stated that surgery should be performed for anatomic reasons versus subjective symptom complaints.

Treatment of Individuals with Patellofemoral Pain

Nonoperative or Conservative Treatment

Literature on the conservative treatment of patellofemoral pain was found to be in general agreement that PFPS should be managed initially by conservative rather than operative means. The length of time which conservative treatment should be continued ranged from 3 months[64] to the more traditional time of 6 months.[65] Conservative treatment is generally considered to consist of any combination of the following elements: education, rest, medication, pain modalities, exercises, EMG biofeedback, patellar taping, and bracing or external supports. Each element will be presented in some detail.

Education. Insall[54] noted that the most important element in conservative management was conveying an understanding of the condition to the patient. Fisher[66] stated that the success of any conservative program for PFPS depended on the cooperation and compliance of a well-informed patient. He also noted that although education can be time consuming, it was effective in relieving anxiety and providing assurance that life or limb threatening pathology did not exist. McConnell[57] specifically noted the importance of the patient having a thorough understanding of the underlying mechanism causing the problem, and the role of treatment in decreasing symptoms.

Medication. The use of aspirin and nonsteroidal antiinflammatory drugs (NSAIDs) was mentioned in numerous articles.[56,65-67] Although aspirin has been found to inhibit the degradation of cartilage in knees subjected to stress,[68] most authors agreed that the clinical effectiveness has not been that impressive.[66] It was generally agreed that NSAIDs may be appropriate, on a short term basis, for patients with severe pain or those not responding to other components of management.[65-67]

Pain Modalities. Continuous ultrasound in the peripatellar area has been advocated[69] but was used in conjunction with other treatment techniques. The benefit of ultrasound alone in the treatment of PFPS is not well documented. The use of cryotherapy to decrease pain and inflammation from activity or exercise is also generally accepted.[65]

Exercise. An extensive amount of literature has been produced on exercise in the management of PFPS, much of which is based on each author's personal experience. There is general agreement that exercise should begin with isometric strengthening of the QF.[52,66,70] Pevsner et al[70] noted that isometric QF strengthening at terminal extension leads to overall QF strength and the VM eventually regains the ability to oppose the forces that pull the patella laterally. McConnell[57] stated that the quality of the QF contraction was the most important component, not the quantity. She defined quality as specific VMO contraction and elimination of the VL, RF, and lateral hamstrings as much as possible. Specific VMO contraction may be facilitated by isometric adductor magnus contraction.[57,71] Emphasis is placed on firing pattern of the QF with the VMO firing first. Monitoring by visual observation and palpation during each contraction is often recommended.[57,70]

Flynn, and Soutas-Little[72] recommended backward running as a form of closed chain strengthening. They found that backward running at a self-selected speed reduced PF joint compressive forces as compared to forward running. McConnell[57] also recommended VMO training in weight bearing, progressing from stance, walk stance position where foot supination and pronation can be worked on, and on stairs where both eccentric and concentric strength can be gained. For more information and details the reader is referred to the original article noted above. The McConnell protocol[57] emphasized the avoidance of pain during exercise and daily activity due to potential quadriceps reflex inhibition, particularly the VMO, in the presence of pain or swelling.

Fisher[66] and Shangold and Mirkin[52] recommended that straight leg raising, using a variety of techniques that vary in the height the leg is lifted, repetitions, and weights used, be included in the rehabilitation process. The use of short arc quadriceps strengthening (SAQ) in terminal ranges, never greater than 45 degrees of flexion has been used.[67,70] Pevsner et al[70] recommended that use of the range of 0 to 45 degrees trained the QF where it was least efficient. Full knee extension with or without resistance was noted to be contraindicated.[54,60]

Swenson et al[65] noted that hamstring strengthening should also be done to maintain the 2:1 quadriceps to hamstring ratio. Along with strengthening, adequate hamstring flexibility is also vital.[56,65] Stretching of the iliotibial band with emphasis on the distal fibers and manual stretching of the lateral retinaculum should also be done either actively or passively.[56]

Return to previous physical level and activities is done slowly. Pevsner et al[70] stated that they were able to more safely increase the strength of the QF throughout the range of motion using functional activities in weight bearing. Likewise, McConnell[57] noted that rehabilitation needs to specifically train the quadriceps to the activity the individual plans to resume.

Many authors indicated the need to do the exercises frequently and at high repetitions. Brooks[73] found that retention and improvement of a skill depended on frequent and continued use. Maring[74] noted the importance of both physical and mental practice. McConnell[57] used the principal "a little bit often" to describe the frequency of exercise performance.

Doucette and Goble[75] found that 84% of the subjects with lateral patellar compression syndrome demonstrated improved patellar tracking with VMO strengthening, iliotibial band and lateral retinaculum stretching, and joint mobility exercises. McConnell[76] stated that 80% of the 500 patients treated using the McConnell protocol for VMO strengthening were completely pain free after four visits. One hundred and seventy of these patients were reviewed 12 months later. All of these patients reported that they had remained pain free and were actively participating in their sports. It was noted that 15% had experienced recurrences of pain but that the pain disappeared once they resumed the VMO training activities.

Willett and Karst[77] recently studied the effect of conservative treatment on the timing and magnitude of VMO and VL contraction in patients with PFPS . While no significant change was found in the relative timing or magnitude of the VMO and VL, a significant reduction in pain was reported by the subjects. The mechanism by which pain relief occurred was noted to be unclear, but that it did not appear to be related to EMG activity of the VMO and VL.

EMG Biofeedback. Wise et al[78] found that the magnitude of the QF electrical activity was of less importance than the VMO:VL ratio. VMO:VL ratios of symptomatic subjects ranged from 1:1.3 to 1:2.6. After use of conventional quadriceps exercises with EMG biofeedback to enhance VMO contraction, the VMO:VL ratio was lowered to 1:1. The 1:1 ratio was found to correlate with pain free quadriceps function.

In 1991, Ingersoll and Knight[79] assessed patellar location changes following EMG biofeedback training of the QF compared to SAQ exercises using progressive resistance exercise principles. EMG biofeedback consisted of feedback designed to increase VMO activity and decreased VL activity. Patellar location was assessed using Merchant's view x-ray. They found that QF group strength changed with the use of SAQ but was not sufficient to change patellar location. The use of EMG biofeedback, however, did significantly

($p < .004$) change the patellar location. The authors concluded that EMG biofeedback training to selectively strengthen the VMO was essential in correcting faulty patellar tracking.

Patellar Taping. McConnell[57] proposed patellar taping to permit a more normal tracking pattern. Normal tracking of the patella was said to enhance VMO activity due to decreased pain. Taping of the patella is specific to each individual and is based on an assessment of the orientation of the patella. Taping is then worn during exercise and functional activities. As VMO activation and strength improves, the patient is weaned off the tape.

The effect of patella taping of patellar position and perceived pain levels during a 0.2 m step down was assessed by Bockrath et al.[80] McConnell's patella taping technique was used to treat 12 patients with PFPS. The results indicated a significant decrease in pain, but no difference was found in the actual patellar position. The authors concluded that the mechanism for pain reduction was unclear. Although this study did not substantiate the use of taping to reposition the patella, it was found to decrease the patient's pain, thereby allowing the subject to exercise with less pain and quadriceps inhibition.

Cerny[43] studied the affect of patellar taping on VMO:VL EMG ratios to assess if taping enhanced VMO firing when performing a step down exercise. He found that while patellar taping decreased the subject's pain by 94%, there was no change in VMO:VL ratio. The author proposed that the benefit of taping therefore may have been due to increased sensory input or the placebo effect.

Bracing or External Supports. The use of orthotics that limit pronation has been shown to be beneficial in subjects where excessive pronation is thought to be the cause of the symptoms.[6,52,56] There are numerous braces with varying designs and purposes available. The general purpose for use has been to provide support for the knee, avoid direct pressure on the patella, alter the resting length of the quadriceps-patella tendon unit, and prevent lateral tracking of the patella.[52,66,81] Benefit from the use of a variety of knee braces on symptomatic individuals ranged from 24% to 93%.[82] In a more recent study, Finestone et al[83] compared the benefit of patellar sleeves with and without a patellar ring to subjects who used no sleeve. Comfort and pain resolution was significantly ($p < .05$) greater in subjects who used a simple sleeve versus those who used a sleeve with a patellar ring. However, no significant difference was found between subjects using a simple sleeve and those receiving no treatment at all.

Swenson et al[65] and McConnell[58] pointed out that mechanical support to maintain proper patellar tracking should be used while VMO is being strengthened, not as a replacement for strengthening.

Operative Treatment

Surgical intervention is generally considered for those individuals with severe and unremitting symptoms despite conservative treatment for 6 months.[23] Fulkerson[51] stated that clinicians should note mechanical factors that may be causing pain. He noted that strain to the lateral retinaculum may cause abnormal tracking, chondromalacia, and onset of a different kind of pain. Therefore, he recommended that an external release be performed early in rehabilitation to avoid residual chondromalacia.

Fulkerson and Shea[56] as well as Fu and Maday[84] noted that lateral release, proximal realignment, and patellar debridement for individuals with

PFPS but normal patellar alignment were contraindicated. However, in subjects where faulty lateral tracking is found, surgical release of the lateral retinaculum is usually recommended. As a result, in theory the patella should have improved function, improved mobility, and decreased pain. It was of interest to note, however, that in a study of 20 cadaver knees, release of the lateral retinaculum had no effect on patellar tracking.[85]

Surgical techniques of proximal realignment or patellar tendon advancement are often recommended for more advanced cases of malalignment, osteoarthritis of the knee, or chondromalacia of the patella.[15] Reider et al[85] did find that following the proximal realignment procedure, there was improved patella tilt and shift medially during extension. Both procedures are considered major surgery, and carry with them high costs, risks, and possibly extensive rehabilitation.

Summary

The treatment of individuals with PFPS needs to be based on a comprehensive evaluation of all components that influence the knee. Based on the evaluation, nonoperative or operative treatment may be appropriate. If nonoperative treatment is recommended, treatment is directed toward the faults and deficits found during the exam. Fulkerson[51] found that 80% of symptomatic patellofemoral disorders responded to nonoperative treatment.

REFERENCES

1. Williams JGP. The foot and chondromalacia-a case of biomechanical uncertainty. *J Orthop Sports Phys Ther.* 1980;2:50-51.

2. Ramig D, Shadle J, Watkins CA, et al. The foot and sports medicine-biomechanical foot faults as related to chondromalacia patallae. *J Orthop Sports Phys Ther.* 1980;2:48-50.

3. Rusche K, Mangine RE. Pathomechanics of injury to the patellofemoral and tibiofemoral joint. In: Mangine RE, ed. *Clinics in Physical Therapy: Physical Therapy of the Knee.* New York: Churchill Livingstone; 1988:31-39.

4. Buchbinder MR, Napora NJ, Biggs EW. The relationship of abnormal pronation to chondromalacia of the patella in distance runners. *J Am Podiatr Assoc.* 1979;69:159-162.

5. Powers CM, Maffucci R, Hampton S. Rearfoot posture in subjects with patellofemoral pain. *J Orthop Sports Phys Ther.* 1995;22:155-160.

6. Eng JJ, Pierrynowski MR. Evaluation of soft foot orthotics in the treatment of patellofemoral pain syndrome. *Phys Ther.* 1993:73:62-68.

7. Magee DJ. *Orthopedic Physical Assessment.* 2nd ed. Philadelphia: WB Saunders; 1992:372-374.

8. Daniels L, Worthingham C. Cited by: Roach KE, Miles TP. Normal hip and knee active range of motion: the relationship to age. *Phys Ther.* 1991;71:656-665.

9. Morrissey MC. Cited by: Roach KE, Miles TP. Normal hip and knee active range of motion: the relationship to age. *Phys Ther.* 1991;71:656-665.

10. Hoppenfeld S. *Physical Examination of the Spine and the Extremities.* New York, NY: Appleton-Century-Crofts; 1976:187-189.

11. Ficat RP, Hungerford DS, eds. Biomechanics. In: *Disorders of the Patello-Femoral Joint.* Baltimore: Williams & Wilkins; 1977:22-35.

12. Huberti HH, Hayes WC. Patellofemoral contact pressures: the influence of Q-angle and tendofemoral contact. *J Bone Joint Surg Am.* 1984;66:715-724.

13. Goodfellow J, Hungerford DS, Zindel M. Patello-femoral joint mechanics and pathology: 1. Functional anatomy of the patello-femoral joint. *J Bone Joint Surg Br.* 1976;58:287-290.

14. Reilly DT, Martens M. Cited by: Ficat RP, Hungerford DS, eds. Biomechanics. In: *Disorders of the Patello-Femoral Joint.* Baltimore: Williams & Wilkins; 1977:22-35.

15. Maquet P. Advancement of the tibial tuberosity. *Clin Orthop.* 1976;115:225-230.

16. Landry GL. Patellofemoral stress syndrome: a common but complex problem. *Compr Ther.* 1988;14:21-28.

17. *Manual of Orthopaedic Surgery.* Park Ridge, IL., American Orthopaedic Association, 1972.

18. Hsu RWW, Himeno S, Coventry MB, Chao EYS. Normal axial alignment of the lower extremity and load-bearing distribution at the knee. *Clin Orthop.* 1990;255:215-227.

19. Woodland LH, Francis RS. Parameters and comparisons of the quadriceps angle of college aged men and women in the supine and standing positions. *Am J Sports Med.* 1992;20:208-211.

20. Horton HG, Hall TL. Quadriceps femoris muscle angle: normal values and relationships with gender and selected skeletal measures. *Phys Ther.* 1989;69:897-901.

21. Schulthies SS, Francis RS, Fisher AG, Van De Graaff KM. Does the Q angle reflect the force on the patella in the frontal plane? *Phys Ther.* 1995;75:24-30.

22. Guerra JP, Arnold MJ, Gajdosik RL. Q angle: effects of isometric quadriceps contraction and body position. *J Orthop Sports Phys Ther.* 1994;19:200-204.

23. Insall J, Bullough PG, Burstein AH. Proximal "tube" realignment of the patella for chondromalacia patellae. *Clin Orthop.* 1979;144:63-69.

24. Beck JL, Wildermuth BP. The female athlete's knee. *Clin Sports Med.* 1985;4:345-366.

25. Sherrington CS. *The Integrative Actions of the Nervous System.* New Haven: Yale University Press; 1906.

26. Gose JC, Schweizer P. Iliotibial band tightness. *J Orthop Sports Phys Ther.* 1989;10:399-407.

27. Winslow J, Yoder E. Patellofemoral pain in female ballet dancers: correlation with iliotibial band tightness and tibial external rotation. *J Orthop Sports Phys Ther.* 1995;22:18-20.

28. Sommer HM. Patellar chondropathy and apicitis, and muscle imbalances of the lower extremities in competitive sports. *Sports Med.* 1988;5:386-394.

29. Radin EL, Yang KH, Riegger C, et al. Relationship between lower limb dynamics and knee joint pain. *J Orthop Res.* 1991;9:398-405.

30. Basmajian JV, Harden TP, Regenos EM. Integrated actions of the four heads of quadriceps femoris: an electromyographic study. *Anat Rec.* 1972;172:15-20.

31. Basmajian JV, Deluca CJ. *Muscles Alive.* 5th ed. Baltimore: Williams & Wilkins; 1985:250-257.

32. Lieb FJ, Perry J. Quadriceps function: an anatomical and mechanical study using amputated limbs. *J Bone Joint Surg Am.* 1968;50:1535-1548.

33. Mariani PP, Caruso I. An electromyographic investigation of subluxation of the patella. *J Bone Joint Surg Br.* 1979;61:169-171.

34. Reynolds L, Levin TA, Medeiros JM, et al. EMG activity of the vastus medialis oblique and the vastus lateralis in their role in patellar alignment. *Am J Phys Med.* 1983;62:61-70.

35. Souza DR, Gross MT. Comparison of vastus medialis obliquus: vastus lateralis muscle integrated electromyographic ratios between healthy subjects and patients with patellofemoral pain. *Phys Ther.* 1991;71:310-316.

36. Boucher JP, King MA, Lefebvre R, Pepin A. Quadriceps femoris muscle activity in patellofemoral pain syndrome. *Am J Sports Med.* 1992;20:527-532.

37. Soderberg GL, Cook TM. An electromyographic analysis of quadriceps femoris muscle setting and straight leg raising. *Phys Ther.* 1983;63:1434-1438.

38. Soderberg GL, Minor SD, Arnold K, et al. Electromyographic analysis of knee exercises in health subjects and in patients with knee pathologies. *Phys Ther.* 1987;67:1691-1696.

39. Hanten WP, Schulthies SS. Exercise effect on electromyographic activity of the vastus medialis oblique and vastus lateralis muscles. *Phys Ther.* 1990;70:561-565.

40. Bose K, Kanagasuntheram R, Osman BH. Vastus medialis oblique: an anatomic and physiologic study. *Orthopedics.* 1980;3:880-883.

41. Karst GM, Jewett PD. Electromyographic analysis of exercises proposed for differential activation of medial and lateral quadriceps femoris muscle components. *Phys Ther.* 1993;73:286-299.

42. Hodges PW, Richardson CA. The influence of isometric hip adduction on quadriceps femoris activity. *Scand J Rehabil Med.* 1993;25:57-62.

43. Cerny K. Vastus medialis oblique/vastus lateralis muscle activity ratios for selected exercises in persons with and without patellofemoral pain syndrome. *Phys Ther.* 1995;75:672-683.

44. Voight ML, Wieder DL. Comparative reflex response times of vastus medialis obliquus and vastus lateralis in normal subjects and subjects with extensor mechanism dysfunction: an electromyographic study. *Am J Sports Med.* 1991;19:131-137.

45. Karst GM, Willett GM. Onset timing of electromyographic activity in the vastus medialis oblique and vastus lateralis muscles in subjects with and without patellofemoral pain syndrome. *Phys Ther.* 1995;75:813-823.

46. Spencer JD, Hayes KC, Alexander IJ. Knee joint effusion and quadriceps reflex inhibition in man. *Arch Phys Med Rehabil.* 1984;65:171-177.

47. Scott W, Huskisson EC. Graphic representation of pain. *Pain.* 1976;2:175-184.

48. Carlsson AM. Assessment of chronic pain. I. Aspects of the reliability and validity of the visual analogue scale. *Pain.* 1983;16:87-101.

49. Price DD, McGrath PA, Rafii A, Buckingham B. The validation of visual analogue scales as ratio scale measures for chronic and experimental pain. *Pain.* 1983;17:45-56.

50. Flandry R, Hunt JP, Terry GC, Hughston JC. Analysis of subjective knee complaints using visual analog scales. *Am J Sports Med.* 1991;19:112-118.

51. Fulkerson JP. The etiology of patellofemoral pain in young, active patients. *Clin Orthop.* 1983;179:129-133.

52. Shangold MM, Mirkin G. *Women and Exercise Physiology and Sports Medicine.* Philadelphia: FA Davis;1988:201-209.

53. Carson WG, James SL, Larson RL, et al. Patellofemoral disorders: physical and radiographic evaluation. *Clin Orthop.* 1994;185:165-177.

54. Insall J. "Chondromalacia patellae": patellar malalignment syndrome. *Orthop Clin North Am.* 1979;10:117-127.

55. McConnell J. *The Advanced McConnell Patellofemoral Treatment Plan.* 1992 Course Manual. Jenny McConnell, BAppSce(Phty), GradDipManTher, MBiomedEng, PO Box 425, Neutral Bay, New South Wales, Australia.

56. Fulkerson JP, Shea KP. Current concepts review disorders of patellofemoral alignment. *J Bone Joint Surg Am.* 1990;72:1424-1429.

57. McConnell J. The management of chondromalacia patellae: a long-term solution. *Australian Journal of Physiotherapy.* 1986;32:215-223.

58. McConnell J. Patella alignment and quadriceps strength. From the Proceedings of the MTAA conference; November 1987.

59. Fitzgerald GK, McClure PW. Reliability of measurements obtained with four tests for patellofemoral alignment. *Phys Ther.* 1995;75:84-90.

60. Kendall FP, McCreary EK. *Muscles, Testing and Function.* 3rd ed. Baltimore: Williams & Wilkins;1983.

61. Shellock FG, Mink JH, Fox JM. Patellofemoral joint: kinematic MR imaging to assess tracking abnormalities. *Radiology.* 1988;168:551-553.

62. Brossmann J, Muhle C, Schroder C, et al. Patellar tracking patterns during active and passive knee extension: evaluation with motion-triggered cine MR imaging. *Radiology.* 1993;187:205-212.

63. Søjbjerg JO, Lauritzen J, Hvid I, Boe S. Arthroscopic determination of patellofemoral malalignment. *Clin Orthop.* 1987;215:243-247.

64. Gruber MA. The conservative treatment of chondromalacia patella. *Orthop Clin North Am.* 1979;10:105-115.

65. Swenson EJ, Hough DO, McKeag DB. Patellofemoral dysfunction: how to treat, when to refer patients with problematic knees. *Postgrad Med.* 1987;82:125-141.

66. Fisher RL. Conservative treatment of patellofemoral pain. *Orthop Clin North Am.* 1986;17:269-272.

67. Chrisman OD. The role of articular cartilage in patellofemoral pain. *Orthop Clin North Am.* 1986;17:231-234.

68. Chrisman OD, Snook GA, Wilson TC. The protective effect of aspirin against degradation of human articular cartilage. *Clin Orthop.* 1972;84:193-196.

69. Meyer JJ, Zachman ZJ, Keating JC, Traina AD. Effectiveness of chiropractic management for patellofemoral pain syndrome's symptomatic control phase: a single subject experiment. *J Manipulative Physiol Ther.* 1990;13:539-549.

70. Pevsner KN, Johnson JRG, Blazina ME. The patellofemoral joint and its implications in the rehabilitation of the knee. *Phys Ther.* 1979;59:869-874.

71. Antich TJ, Brewster CE. Modification of quadriceps femoris muscle exercises during knee rehabilitation. *Phys Ther.* 1986;66:1246-1250.

72. Flynn TW, Soutas-Little RW. Patellofemoral joint compression forces in forward and backward running. *J Orthop Sports Phys Ther.* 1995;21:277-282.

73. Brooks VB. Motor control: how posture and movements are governed. *Phys Ther.* 1983;63:664-673.

74. Maring JR. Effects of mental practice on rate of skill acquisition. *Phys Ther.* 1990;70:28-35.

75. Doucette SA, Goble EM. The effect of exercise on patellar tracking in lateral patellar compression syndrome. *Am J Sports Med.* 1992;20:434-440.

76. McConnell J. Training the vastus medialis oblique in the management of patellofemoral pain. *Proceedings of the 10th International Congress of the World Confederation for Physical Therapy; Sydney, New South Wales, Australia;* 1987.

77. Willett GM, Karst GM. Patellofemoral disorders: is timing or magnitude of vastus medialis obliquus and vastus lateralis muscle activity affected by conservative treatment? Presented at 1995 American Physical Therapy Association Combined Sections Meeting; February 1995; Reno, NV.

78. Wise HH, Fiebert IM, Kates JL. EMG biofeedback as treatment for patellofemoral pain syndrome. *J Orthop Sports Phys Ther.* 1984;6:95-103.

79. Ingersoll CD, Knight KL. Patellar location changes following EMG biofeedback or progressive resistive exercises. *Med Sci Sports Exerc.* 1991;23:1122-1127.

80. Bockrath K, Wooden C, Worrell T, et al. Effects of patella taping on patella position and perceived pain. *Med Sci Sports Exerc.* 1993;25:989-992.

81. Hunter LY. Women's athletics: the orthopedic surgeon's viewpoint.*Clin Sports Med.* 1984;3:809-827.

82. Villar RN. Patellofemoral pain and the infrapatellar brace: a military view. *Am J Sports Med.* 1985;13:313-315.

83. Finestone A, Radin EL, Lev B, et al. Treatment of overuse patellofemoral pain. Prospective randomized controlled clinical trial in amilitary setting. *Clin Orthop.* 1993;293:208-210.

84. Fu FA, Maday MG. Arthroscopic lateral release and the lateral patellar compression syndrome. *Orthop Clin North Am.* 1992;23:601-612.

85. Reider B, Marshall JL, Ring B. Patellar tracking. *Clin Orthop.* 1981;157:143-148.