

# The effect of exercise on patellar tracking in lateral patellar compression syndrome

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## ABSTRACT

The influence of a physical therapy program on pain and patellar tracking was investigated clinically and radiologically with tangential views in 51 knees with lateral patellar compression syndrome. A pretest-posttest design was used to evaluate physical measurements of patellar alignment in subjects who had had patellofemoral pain for a minimum of 6 weeks. Eighty-four percent of the subjects were pain-free after an average of 8 weeks of rehabilitation or 11 physical therapy visits, with a mean quadriceps strength to total body weight ratio of 61% in women and 86% in men. The pretest-posttest difference in Merchant's congruence angle was significant at a probability of 0.0066 in the patients who were pain-free after exercise, demonstrating less lateral patellar tracking. The pretest-posttest difference in iliotibial band flexibility was significant at a probability of 0.0017, with the patients who were pain-free after exercise becoming more flexible. No significant differences were observed from before to after exercise in the patellofemoral index, Q angle, hamstring flexibility, thigh measurement, sclerotic subchondral bone, or sulcus angle. We were unable to predict which subjects would become pain-free with exercise by patellar position because the group that improved began more laterally tilted. The results of this study indicate that patellar tracking is improved with vastus medialis oblique strengthening, iliotibial band stretching, and joint mobility exercise in the majority of subjects with lateral patellar compression syndrome.

Patellofemoral pain is one of the most common knee complaints encountered in sports medicine clinics. Patellofemoral pain is usually located in the retropatellar or peripatellar regions and is described as a dull ache or throbbing feeling. The pain is aggravated by activities involving increased

patellofemoral compressive forces such as sitting with the knees bent, ascending or descending stairs, kneeling, and squatting. Other symptoms include swelling, giving way, popping, catching, or locking.

A thorough physical examination is necessary in the evaluation of the patellofemoral joint, and should include inspection of the patella and lower extremity alignment and patellar tracking through the knee range of motion; vastus medialis oblique (VMO) dysplasia and atrophy; patellofemoral joint compression for retropatellar pain; apprehension; patellar crepitus; effusion; Q angle; medial and lateral patellar facets for tenderness; lateral retinaculum for tightness; medial retinaculum, quadriceps, and patellar tendon; iliotibial band, hamstring, hip flexors, and gastrocnemius flexibility; and gait analysis. It is necessary to evaluate the collateral and cruciate ligaments, menisci, and rotatory stability as well as retinacular pain, the plica, the fat pad, patellar tendinitis, bursitis, and referred pain. Basic radiologic evaluation includes AP, lateral, and axial views.

The causative factors of patellar tracking dysfunction include deficiency of supporting muscles and guiding mechanisms, bony abnormalities, malalignment of the lower extremity, and trauma. Deficiencies of patellar stabilizers may be due to abnormalities of the quadriceps femoris and its expansions, including atrophy or aplasia of the VMO,<sup>5,10,12,18</sup> laxity of the medial retinaculum,<sup>3,5,12</sup> lateral retinaculum tightness,<sup>12,18</sup> iliotibial band tightness, hamstring tightness,<sup>5,7,10</sup> gastrocnemius tightness, and elongated patellar tendon or patella alta.<sup>3,5,10,18</sup> Bony abnormalities include shallow lateral femoral condyles,<sup>5,10,12,18</sup> as well as irregularities in the size and shape of the patella.<sup>5,12</sup> Malalignment of the lower extremity—including increased Q angle,<sup>2</sup> genu valgum,<sup>9,12</sup> genu recurvatum,<sup>6</sup> femoral anteversion,<sup>5,10</sup> lateral displacement of the tibial tubercle or external tibial torsion,<sup>10</sup> and excessive foot pronation—also increase the tendency of the patella to displace laterally. Trauma may also play a role in the occurrence of patellofemoral pain by acute direct injury, by the indirect effects of an effusion, or by the chronic repetitive stress of running.<sup>9</sup>

The cause of patellofemoral pain is obscure, although it is

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generally accepted as being secondary to patellar malalignment. Radiographs of the axial view of the patellofemoral joint have demonstrated inconsistent findings between pain and lateral tilt. It is also difficult to explain patellofemoral pain because hyaline articular cartilage is devoid of nerve fibers and patellar articular appearance often correlates poorly with patients' symptoms.<sup>9</sup>

Many hypotheses for patellofemoral pain have been proposed. Lateral malalignment is hypothesized to cause hyperpressure of the lateral patellofemoral compartment and hypopressure of cartilage on the patellar and femoral surfaces of the medial patellofemoral joint.<sup>10,15</sup> Hypopressure and disuse of the medial patellar facet may cause malnutrition and early degenerative changes of the articular cartilage because of lack of normal kneading and function. This may explain why early chondromalacia patellae is usually noted on the medial patellar facet, late chondromalacia (after age 30) lesions are noted on both patellar facets, and patellofemoral osteoarthritis is more advanced and common in the lateral patellar facet.<sup>15</sup>

Degeneration or softening of articular cartilage provokes a chemical synovitis and then effusion. The synovium, which has a rich nerve supply, may become irritated and produce pain.<sup>9</sup> However, many patients with patellofemoral pain have an intact articular surface with no evidence of local synovial irritation.<sup>9</sup>

The subchondral bone also has a rich nerve supply and thus may be the origin of pain. Goodfellow et al.<sup>8</sup> describe a lesion termed "basal degeneration" that consists of fibrillation of collagen in the middle and deep zones of cartilage and does not affect the articular surface initially. An increase in metaphyseal intraosseous pressure has been shown to produce pain. Therefore, failure of the energy absorption function on the articular cartilage should cause an increase in the intraosseous pressure of the patellar subchondral bone and thus produce pain.<sup>9</sup>

It is generally accepted that conservative rehabilitation brings relief of symptoms to the majority of patients with patellofemoral pain. The basis of conservative treatment is to strengthen the VMO, whose fibers provide the main counteraction to lateral patellar tracking. Conservative treatment often involves a combination of the following measures: VMO strengthening exercises, ice, ultrasound, electrical galvanic stimulation, patellar mobilizations, non-steroidal antiinflammatory medications, faradic stimulation, biofeedback, patellar taping, hamstring, iliotibial band, and gastrocnemius stretching, shoe orthoses, knee sleeves, infra-patellar bracing, and walking aids.<sup>2,11,13,14,16,17,19,20,25</sup>

It is unclear why patellofemoral pain decreases with exercise. It has been suggested that exercise improves patellar tracking, decreases patellofemoral contact forces, improves the nutrition of the joint, and decreases edema, but studies to justify any of these hypotheses are scarce. The purpose of this study was to determine the effect of exercise on patellar tracking and pain in patients with lateral patellar compression syndrome.

## MATERIALS AND METHODS

### Population and sample

Fifty-six knees were studied in 28 subjects. Subjects for this study were those in whom lateral patellar compression syndrome was diagnosed after clinical and radiologic evaluation. Inclusion in the study required the presence of patellofemoral pain for a minimum of 6 weeks, evidence of patellar tilt on axial view radiographs, and no secondary knee complications. There were no restrictions on age or gender. Most of the following symptoms were demonstrated during the physical examination: VMO atrophy, reduced transverse patellar play, pain with patellofemoral joint compression in varying degrees of flexion, patellar crepitus, medial or lateral patellar facet tenderness, increased Q angle, positive apprehension test, tightness in the lateral retinaculum and iliotibial band, and excessive lateral patellar tracking with quadriceps contraction and throughout the range of knee motion.

Following the rehabilitation program the patients were divided into three groups: those who were pain-free after exercise (Group 1), those who had pain after exercise (Group 2), and a control group (Group 3) made of the uninvolved knees of five subjects with unilateral pain. Although unilateral pain was present, the contralateral knee was used to help determine if there was malalignment in both knees when only one knee was symptomatic.

### Design

A pretest-posttest design was used for this study. The patients were referred for physical therapy, after which they were set up with individualized exercise programs. At the time of the initial and final physical therapy visits the following information was recorded: subjective pain, age, sex, weight, height, duration of physical therapy, stage of treatment, normal activity level, thigh difference, hamstring flexibility, iliotibial band flexibility, sclerotic subchondral bone, foot pronation, sulcus angle, leg-length difference, patellofemoral congruence angle, patellofemoral index, and Q angle. When the affected knees became pain-free or when conservative measures were unsuccessful, follow-up radiographs were taken.

Information for the clinical physical therapy evaluations was obtained using the following methods. Subjects completed the history and pain form. Thigh measurements were taken bilaterally at 20% and 50% of the distance from the lateral knee joint line to the greater trochanter. Hamstring flexibility was measured with the subjects supine and hips flexed to 90°. Complete knee extension in this position was considered normal and deficits were measured with a goniometer. Iliotibial band flexibility was measured with the subjects in Ober's position and was defined as the distance between the medial patella and the table. A goniometer was also used to measure Q angle with the proximal arm positioned toward the anterior superior iliac spine, the pivot point over the center of the patella, and the distal arm along the patellar tendon to the tibial tuberosity. This measure-

ment was taken with subjects in two positions: supine, with both legs fully extended and the quadriceps relaxed, and standing, which is a more functional position.

Pronation was evaluated both statically, with subjects in the standing position, and dynamically and was rated as normal, mild, moderate, or severe. Leg length was measured from the anterior superior iliac spine to the medial malleolus with the subject supine, and by observation of the anterior superior iliac spine, posterior superior iliac spine, iliac crest, gluteal folds, fibular head, and malleoli bilaterally with the subjects standing. Radiographic evaluation of sclerotic subchondral bone and sulcus angle was made by axial view. Sclerotic subchondral bone on the medial and lateral patellar facets of the initial and final radiographs were examined by an orthopaedic surgeon and a radiologist. The sulcus angle was measured from the highest point of the medial and lateral femoral condyles and the lowest point of the intercondylar sulcus.

### Radiology

The axial or tangential projection, which is frequently referred to as the "sunset" or "skyline" view, provides the best information regarding the patellofemoral joint and was used in this study. An axial view apparatus was used to produce accurate, reproducible radiographs. It consists of a knee support and cassette holder that act as a jig to align the patient and film to produce consistent axial radiographs. The patient was positioned supine with the femur resting parallel to the table top and knees placed at approximately 30° of flexion. The calves were strapped together to control rotation because even a small amount of external femoral rotation can falsely simulate a low lateral condyle. A 10 × 12-inch film cassette rested on the patient's shins and against the angled uprights of the axial viewer. The angle of the central beam was 30° from vertical. A lead shield covered the patient's internal organs. Initial exposure factors using a 8:1 grid cassette were 100 mA, 0.20 second, approximately 6 cm thickness, a peak of 76 to 80 kV, and approximately 1 meter (3 feet) of tube-film distance.

### Radiographic evaluation

The congruence angle described by Merchant et al.<sup>21</sup> was used to evaluate the degree of congruence of the patellofemoral joint. To make this measurement, the sulcus angle was bisected to establish a zero reference line. A second line was then projected from the apex of the sulcus angle through the lowest point on the articular ridge of the patella. The angle measured between these two lines is the congruence angle. To help ensure reproducibility of lines, a straight edge resting on the medial and lateral epicondyles was raised to determine the lowest point on the articular ridge of the patella and each measurement was repeated. If the apex of the patellar articular ridge was lateral to the zero line, the congruence angle was designated positive; if it was medial, the congruence angle was negative. The average congruence angle in normal subjects is -6° (SD, 11°). Merchant et al.<sup>21</sup>

found no significant difference when analyzing for sex, age, and side; that a congruence angle of +16° is abnormal at the 95th percentile; and that the average congruence angle of 25 knees with recurrent dislocation was +23°.

The patellofemoral index is the ratio between the thickness of the medial patellofemoral interspace and the lateral patellofemoral interspace. The lateral patellofemoral interspace corresponds to the shortest distance between the lateral patellar facet and the articular surface of the lateral femoral condyle. The medial patellofemoral interspace is measured by calculating the shortest distance between the lateral limit of the medial patellar facet and the medial femoral condyle.<sup>15</sup> Again, each measurement was repeated. Laurin et al.<sup>16</sup> demonstrated, in axial view radiographs of the patellofemoral joint at 20° of flexion, that normal subjects have ratios of 1.6 or below and subjects with chondromalacia of the patella have ratios of 1.6 and above. This abnormal patellofemoral index, noted in 93% of chondromalacia patients, is likely due to a mini-tilt of the patella with relative widening of the medial interspace.<sup>15</sup>

At 30° of knee flexion, the patella should be well seated and centered in the sulcus; this is the position most likely to show any subluxation radiologically.<sup>5</sup> Merchant's congruence angle is an excellent indicator of patellar centralization and subluxation and may be applied to tangential radiographs at any degree of knee flexion as well as the 45° angle originally described by Merchant.<sup>8</sup> The Laurin view<sup>16</sup> (at 20° of knee flexion) is difficult to obtain. For these reasons, and since the pretest-posttest design of this study allowed us to observe change in congruence angle or patellofemoral index as well as differences among groups, a 30° knee flexion angle was chosen.

### Rehabilitation program

An individualized, comprehensive, five-stage physical therapy program was designed to meet each subject's specific needs using the exercises and rationale presented in Table 1. Patellofemoral pain and edema cause reflex inhibition of the VMO and hence were contraindications to exercise. Isokinetic strength testing was performed during Stage 4. Subjects remained at this stage until they were able to test to 85% of the strength in their uninvolved knees. When both legs were involved, subjects were given a final test when they were pain-free.

## RESULTS

### Descriptive statistics

Eighty-four percent of the knees became pain-free with conservative exercise programs (Group 1). Sixteen percent of the knees did not respond to exercise (Group 2). Table 2 provides the means and standard deviations for Group 1 (25 subjects, 43 knees), Group 2 (5 subjects, 8 knees), and Group 3 (the control group). The average ages of the subjects in these groups were: Group 1, 22.9; Group 2, 21.7; and Group

TABLE 1  
Therapeutic exercise program for lateral patellofemoral compression syndrome

Therapeutic Exercise <sup>a</sup>	Rationale	Therapeutic Exercise <sup>a</sup>	Rationale
<b>Stage 1</b>			
Instruction in proper body mechanics (avoid hyperextended and fully extended knees, knee flexion beyond 60°, kneeling, squatting, prone lying, etc.)	From full knee extension to full flexion, the patella moves along a pattern of an arc that is open laterally. Patellar contact stress is usually greatest at 65°. By maintaining a position of knee flexion between 20° and 60° there will be a decrease in lateral patellofemoral compression	Cartilage compression/distraction and gliding activities: biking with high seat position (15° knee flexion in extended leg), toe clips, and progressing from 0 to moderate resistance. Also, cross-country skiing, flutter kick swimming, walking, etc.	Nutrition of the cartilage is enhanced by joint motion that squeezes synovial fluid in and out of the cartilage matrix to allow adequate diffusion to the chondrocytes. Biking with toe clips enhances VMO stimulation.
Ice, electrical galvanic stimulation, ultrasound, antiinflammatory medication, knee sleeves (with open knee and lateral buttress)	Modalities used to decrease edema and pain in the acute knee	<b>Stage 3</b>	
Orthoses	To decrease excessive foot pronation	Advanced VMO strengthening: Open chain exercise: Continued SLR and SAQ from 5 pounds to ~10% of body weight. Middle and high-speed isokinetic exercises with extension and flexion stops	These open chain exercises (the foot is free) are isolated movements used specifically for VMO strengthening using primarily concentric muscle contractions in a single plane. Extension and flexion stops are used for isokinetic strengthening in a
<b>Stage 2</b>			
VMO strengthening: 1) isometric quadriceps sets at 20° of flexion; 2) SLR supine with femur externally rotated and knee at 20° of flexion and opposite knee bent (slowly raise leg); 3) SAQ Supine with roll under thigh and knee flexed to 50° and leg externally rotated, extend knee to 20°; 4) Hip adduction—side lying on involved side with 20° bend in knee, lift toward ceiling, progress from 5 sets of 10 repetitions to 10 of 10. SLR and SAQ progressed from 0 to 5 pounds of resistance. Patellofemoral discomfort was a contraindication to exercise.	Exercise to strengthen the VMO, the major medial dynamic stabilizer of the patella. The femur is in an externally rotated position because most of the VMO originates from the tendon of the adductor magnus.	Closed chain exercises: progressive steps, squats, hip sled, rubber tubing exercises such as the seated leg press, single knee dips, double knee dips, resistive walking, balance board activities for foot supinators and invertors.	The extensor mechanism acts to extend the knee and decelerate the body's momentum. These closed chain exercises (foot is in a fixed position) are more functional because they provide eccentric, concentric, and isometric muscle contractions. They work the quadriceps in functional movement patterns, which exercise joints and muscles synergistically. This facilitates proprioceptive and kinesthetic awareness.
Neuromuscular stimulation of the VMO	May be used to enhance muscle contraction and to help educate patient to location of VMO	<b>Stage 4</b>	
Medial patellar taping <sup>20</sup>	At lower flexion angles, the effect of a lateral imbalance manifests as a rotation of the patella in the coronal plane, while at higher flexion angles, the imbalance is more likely to produce a change in tilt of the patella in the sagittal plane. <sup>1</sup> Patellar taping often allows pain-free exercise by decompressing and derotating the patella.	Advanced VMO strengthening continued: Full-spectrum, full knee range of motion isokinetics and double rubber tubing exercises.	Full range strengthening is incorporated since 60% more muscular effort is required to extend the knee through the last 15° than is required through the rest of the knee joint range of motion. <sup>12</sup>
<b>Stage 5</b>			
Stretching: Hamstring, gastrocnemius, and hip flexor	Improve flexibility to decrease patellofemoral compression during dynamic activities.	Return to sports participation. Independent maintenance home exercise program.	Independent program of VMO strengthening, flexibility exercises, and cartilage compression/distraction and gliding activities to ensure proper patellar tracking and to enhance cartilage nutrition are important to maintain a pain-free status.
Iliotibial band (Ober's position and standing with involved leg posterior and across opposite leg and leaning toward opposite leg) and lateral retinaculum (via patellar mobilizations with tilts and medial glides) stretching	Stretch structures providing lateral stabilization.		

<sup>a</sup> SLR, straight leg raising; SAQ, short arc quadriceps.

TABLE 2  
Means and SDs of patellar tracking variables

Variable <sup>a</sup>	Group 1		Group 2		Group 3	
	Mean	SD	Mean	SD	Mean	SD
Quad Tendon/BW %	62.80	14.90				
Age	22.90	11.19	21.75	9.72	16.00	2.55
Pain duration (days)	55.00	74.45	38.13	24.18		
Initial pain rating <sup>b</sup>	5.12	1.93	6.38	1.77		
Post pain rating	0.06	7.12				
Pre congruence angle	8.03	20.14	-8.63	13.42	-21.10	19.98
Post congruence angle	1.41	20.20	2.13	13.63	-18.10	21.40
Pre PFI	1.70	0.58	1.47	0.26	1.11	0.07
Post PFI	1.71	0.69	1.65	0.30	1.13	0.07
Q angle						
Pre, supine	17.65	3.81	18.62	2.67	17.20	2.68
Post, supine	16.53	5.32	18.50	2.93	16.80	3.35
Pre, standing	17.86	3.31	19.75	2.05	17.00	2.55
Post, standing	16.55	5.06	19.38	2.56	17.00	3.39
Pre hamstring flexibility <sup>c</sup>	20.86	15.88	25.50	18.27	24.40	16.01
Post hamstring flexibility	9.09	11.11	15.25	17.30	9.80	12.26
Pre ITB flexibility (cm)	15.86	5.25	13.00	4.69	14.60	6.31
Post ITB flexibility (cm)	11.23	4.27	16.50	6.41	11.00	5.24
Thigh measurement (cm)						
Pre 20%	39.21	3.49	42.48	4.30	39.26	2.75
Post 20%	39.52	3.30	44.00	6.50	39.62	2.50
Pre 50%	49.32	3.87	53.51	4.89	49.38	2.67
Post 50%	49.74	3.68	54.36	7.20	49.22	2.83
Pronation <sup>d</sup>	2.05	0.95	2.13	0.99	2.80	1.10
Sulcus angle (deg)	142.26	7.55	140.75	4.40	137.40	3.85
Exercise stage	4.33	1.17	2.75	2.31		
Duration of exercise	2.11	1.67	3.59	1.80		
PT visits	11.00	14.30	11.00	4.47		
Normal activity levels <sup>e</sup>	2.30	0.71	1.88	0.64	2.80	0.21

<sup>a</sup> PFI, patellofemoral index; ITB, iliotibial band.

<sup>b</sup> Subjective ratings taken on a scale of 0 to 10, with 0 being no pain and 10 being the worst pain ever experienced.

<sup>c</sup> Norm for hamstring flexibility is 0°.

<sup>d</sup> Scale: 0, normal; 1, mild; 2, moderate; 3, severe.

<sup>e</sup> Scale: 1, low; 2, moderate; 3, high.

3, 16. Eighty-nine percent (25) of the subjects were women. Thirty-five percent of Group 1 initially described the pain as constant, while 65% described it as intermittent. In Group 2, 12% described the pain as constant, and 88% described it as intermittent. Pain was initially described as a combination of the following in Groups 1 and 2, respectively: sharp (53% and 100%), dull (19% and 50%), aching (72% and 75%), and throbbing (28% and 50%). Both Groups 1 and 2 found the following activities painful: walking (47% and 50%), running (81% and 75%), climbing stairs (79% and 75%), and sitting (51% and 75%), respectively. Jumping, squatting, kneeling, bending, and stooping were also reported as painful activities. Both Groups 1 and 2 reported pain before activity (47% and 12%), after activity (93% and 88%), during activity (100% and 100%), and at rest (47% and 63%). Twenty-eight percent of Group 1 and all of Group 2 were taking antiinflammatory medications.

Hamstring flexibility improved in all groups. The thigh measurement increase in Group 2 may be attributed to one subject (two knees), who gained 30 pounds. A leg-length difference was observed in 14% of the subjects. An orthopaedic surgeon and a radiologist were unable to observe any

differences in sclerotic subchondral bone in patellar facets on pretest and posttest radiographs. There were no significant differences found between groups in sulcus angle.

Subjects in Group 1 became pain-free after an average of 8 weeks of treatment, while Group 2 subjects showed no decrease in symptoms after an average of 14 weeks. Both Groups 1 and 2 had an average of 11 physical therapy visits.

Of the eight knees that did not respond to conservative treatment, 50% had arthroscopic surgery for lateral retinacular release. From this group, 75% also had removal of medial synovial plicae, 25% had excisions of impinging fat pads, and 25% had synovectomies.

#### Analysis of variance

One-way analysis of variance (ANOVA) was performed on the differences in the dependent variables between pretest and posttest for each group. For all tests, alpha was set at 0.05 for a 95% confidence interval. A significant difference was seen in pretest to posttest congruence angles in Group 1. Group 1 demonstrated a mean decrease in congruence angles of 6.62°, indicating more medial tracking, which was significant ( $P = 0.0066$ ).

A significant difference was found between pretest and posttest iliotibial band flexibility, which improved an average of 4.63 cm in Group 1 ( $P = 0.0017$ ).

The Fisher Protected Least Significant Difference (PLSD), a multiple comparisons test, was used to determine differences between pretest and posttest group scores. There were differences between Groups 1 and 2 for congruence angles, and between Groups 1 and 2, as well as Groups 2 and 3, for iliotibial band flexibility at a 95% significance level.

Pain ratings decreased an average of 5.0 in Group 1, which was significant compared to an increase of 0.75 in Group 2. No significant differences were seen between before and after exercise measurements of differences in Q angle supine or standing, the patellofemoral index, or hamstring flexibility.

One-way ANOVA was also performed on these groups for each dependent variable to help establish significance among the three groups. Initial congruence angles were significantly different among groups ( $P = 0.0028$ ). Initial measurement averages demonstrated Group 1 to be most laterally tilted at +8.0321°, Group 2 to be more centrally positioned at -8.625°, and Group 3 more medially positioned at -21.1°. The Fisher PLSD test demonstrated significant differences between Groups 1 and 2 and Groups 1 and 3.

One-way ANOVA demonstrated significant differences in initial patellofemoral index between Groups 1 and 3 ( $P = 0.0486$ ; Fisher PLSD = 0.4967). Group 1 was more laterally tilted at a mean of 1.7 and Group 3 more centrally positioned at 1.1.

The control group demonstrated means for congruence angle and patellofemoral index at 30° of knee flexion that were closely related to the normative data presented by Merchant et al.<sup>21</sup> at 45° and Laurin et al.<sup>16</sup> at 20° of knee flexion. Groups 1 and 2 demonstrated means that were more

closely associated with Laurin's chondromalacia patients and less laterally tilted than Merchant's recurrent dislocation patients.

When preexercise paired *t*-tests were used to compare the pain-free knee with the contralateral painful knee, there was no significant difference in patellofemoral index or in congruence angle. This may be due to the small number of subjects with unilateral pain in this study; thus, further research is warranted.

Postexercise iliotibial band flexibility was shown to be significantly different among groups ( $P = 0.0174$ ). Average postexercise means of Groups 1, 2, and 3 were 11.2, 16.5, and 11.0, respectively. The Fisher PLSD test result was significant at 95% for Group 1 versus Group 2, and for Group 2 versus Group 3.

Significant differences ( $P = 0.005$ ) were seen between groups on exercise stage attained and duration of exercise. Group 1 averaged Stage 4.33 and 8 weeks of exercise, whereas Group 2 averaged Stage 2.75 and 14 weeks of exercise. A chi-square test was performed and demonstrated no significant differences between male and female subjects. One-way ANOVA was performed on sex versus dependent variables, and the differences between pretest- and posttest-dependent variables. There was a significant difference ( $P = 0.004$ ) seen in quadriceps strength to total body weight ratio, with a mean of 61% for women and 86% for men. The only other significant difference was the change in hamstring flexibility ( $P = 0.033$ ). Women demonstrated an average improvement of 21.67°, while men improved an average of 10.58°.

Fourteen percent of the subjects had leg-length discrepancies. One-way ANOVA was performed on right versus left legs for the dependent variables. The only significant difference observed was that right legs were generally longer than the left legs ( $P = 0.065$ ).

## DISCUSSION

It appears from the significant differences between before and after exercise congruence angles in the group with no pain that exercise does influence patellar tracking. This group demonstrated an average decrease in congruence angle of 6.6°, indicating a more medial tilt of the patella after attaining an average exercise stage of 4.33. Ahmed et al.<sup>1</sup> have demonstrated that if the tension in the VMO is removed, the pressure zone shifts almost entirely to the lateral facet of the patella. Any variation in the lateral balance of the patella created by an alteration in the lines of action or in the magnitudes of the tensions in the VMO and vastus medialis longus has been found to have a pronounced influence on the location and orientation of the pressure zone.<sup>1</sup> This study confirms that centralization of the patella is possible with VMO strengthening in lateral patellar compression syndrome.

Moller et al.<sup>22</sup> found significant decreases in patellar congruence angles after 3 months of isometric quadriceps setting exercises (15 minutes four times a day) in 15 knees with patellar subluxation, but no significant changes were seen

in 21 knees with anterior pain or in 50 nonsymptomatic knees. Only 7 subjects were pain-free after 3 months of isometric quadriceps exercises. A diagnosis of lateral patellar compression syndrome was made of the subjects in this study, who are more closely related to the group with anterior knee pain in the study by Moller et al. Our findings are contradictory to that study in that we found significant differences in congruence angles before and after testing; however, this study used a more comprehensive exercise program, including aggressive VMO strengthening techniques and stretching procedures.

Although 43 knees became pain-free, no significant pretest to posttest differences were demonstrated in the patellofemoral index. Laurin et al.<sup>16</sup> demonstrated that knee flexion beyond 20° will bring some abnormally aligned patellae back into the trochlear sulcus. Taking tangential radiographs at 30° of knee flexion, instead of 20°, may have caused some subtle tracking differences to have been missed.

Iliotibial band flexibility is a factor that is often overlooked in many rehabilitation programs. Significant pretest to posttest differences in iliotibial band flexibility were seen in the group with no pain. The patients in Group 1 were able to improve their flexibility pretest to posttest by an average of 3.8 cm, while those in Group 2 decreased in flexibility by an average of 3.5 cm. Postexercise iliotibial band flexibility lacked an average of 16.5 cm for Group 2 and 11.2 cm for Group 1. The majority of subjects in all groups had poor initial hamstring flexibility, but were improved after exercise. Iliotibial band flexibility was one of the few differences that could be measured clinically between subjects that improved and those that did not.

Fulkerson and Hungerford<sup>6</sup> describe excessive lateral pressure syndrome (ELPS) as the result of chronic lateral patellar tilt, adaptive lateral retinaculum shortening, and the resultant chronic imbalance of facet loads. They state, "After considering all the evidence, one is led to the conviction that excessive tension in the lateral retinaculum is, indeed, a major contributing factor in most cases of ELPS."<sup>6(p115)</sup> Our study confirms the importance of iliotibial band flexibility in patellar tracking problems with significant improvements in flexibility seen in 43 patients with no knee pain after exercise. The greater part of the lateral retinaculum originates at the iliotibial band, and thus stretching of both structures is an important aspect of rehabilitation of the patient with patellofemoral pain.

Cartilage chondrocytes die from excessive pressure, lack of pressure, or absolute immobilization, all of which prevent fluid flow.<sup>23</sup> To improve articular cartilage nutrition in the patellofemoral joint, intermittent compression and decompression and gliding mobility exercises should be included in the rehabilitation program. Exercise decreases synovial fluid viscosity and increases diffusion of nutrients to cartilage.<sup>4,28</sup> In addition, it has been shown radiographically that the thickness of the cartilage layer can increase during exercise.<sup>26</sup> Therefore, a comprehensive exercise program must include lateral retinaculum and iliotibial band stretching to eliminate excessive lateral patellar facet hy-

perpressure, VMO strengthening to correct medial facet hypopressure, and joint mobility exercises to improve cartilage nutrition.

Based on the measured variables, there was no way to predict which subjects would become pain-free and which would require surgery. As a group, subjects who were pain-free after exercise had a more laterally positioned patella for initial congruence angle and patellofemoral index, so a more severe lateral patellar tilt was not the reason for the lack of response in Group 2. This group demonstrated average increases or more lateral tilt from pretest to posttest in congruence angle and patellofemoral index.

There are several possible explanations for the increase in lateral tilt and pain observed in Group 2, including a decrease in iliotibial band flexibility, an adaptively shortened lateral retinaculum, an increased inflammatory response, and secondary knee complications. Iliotibial band tightness may be responsible for an increased lateral patellar tilt and lateral patellofemoral compression forces. An adaptively shortened lateral retinaculum will not only perpetuate, but may actually aggravate an existing patellar lateralization or tilt of the patella.<sup>6</sup> With inflammation, polymorphonuclear granulocytes, which are responsible for phagocytosis of foreign or damaged materials, may attack cartilage and joint tissue.<sup>24</sup> Also, during inflammatory states there is decreased absorption of essential nutrients by the cartilage. This increased inflammation may be responsible for the increase in pain rating by irritating the fibrous capsule's richly endowed nerve endings or by increasing the intraosseous pressure of subchondral bone. The increase in pain may also be due to other complications such as irritation to the medial synovial plica, fat pad impingement, or synovitis.

Traditionally, patellofemoral pain has been thought of as a condition that affects overweight adolescent girls with genu valgum. Eighty-nine percent of the subjects in this study were adolescent girls, but the majority were thin and athletic. Hughston et al.<sup>12</sup> also found patellar tracking dysfunction in an athletic population, but the dysfunction in their study was more evenly distributed between men and women. Twenty-four percent of the subjects in their study were adolescents. Conservative care is important with this group since the patellofemoral joint can undergo further development during the last several years of growth.<sup>12</sup>

In this study, 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. A trial of therapeutic exercise seems appropriate since there was no way to predict the success of conservative care based on patellar position.

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## REFERENCES

1. Ahmed AM, Burke DL, Yu A: In-vitro measurement of static pressure distribution in synovial joints-part 2: Retropatellar surface. *Trans ASME* 105: 226-236, 1983
2. Bose K, Kanagasuntherum R, Osman M: Vastus medialis oblique: An anatomical and physiologic study. *Orthopedics* 3: 880-883, 1980
3. Brattstrom H: Shape of the intercondylar groove normally, and in recurrent dislocation of the patella. *Acta Orthop Scand* 68: 1-48, 1964
4. Curtiss PH: Changes produced in the synovial membrane and synovial fluid by disease. *J Bone Joint Surg* 46A: 873-888, 1964
5. Ficat RP, Hungerford DS: *Disorders of the Patellofemoral Joint*. Baltimore, Williams & Wilkins, 1977
6. Fulkerson JP, Hungerford DS: *Disorders of the Patellofemoral Joint*. Second edition. Baltimore, Williams & Wilkins, 1990
7. Goodfellow JW, Hungerford DS, Woods C: Patello-femoral joint mechanics and pathology. II: Chondromalacia patellae. *J Bone Joint Surg* 58B: 291-299, 1976
8. Goodfellow JW, Hungerford DS, Zindel M: Patello-femoral joint mechanics and pathology. I: Functional anatomy of the patello-femoral joint. *J Bone Joint Surg* 58B: 287-290, 1976
9. Grana WA, Hinkley B, Hollinsworth S: Arthroscopic evaluation and treatment of patellar malalignment. *Clin Orthop* 186: 122-128, 1984
10. Grana WA, Kriegshauser LA: The scientific basis of extensor mechanism disorders. *Clin Sports Med* 4: 247-257, 1985
11. Gruber MA: The conservative treatment of chondromalacia patellae. *Orthop Clin North Am* 10: 105-115, 1979
12. Hughston JC, Walsh WM, Puddu G: *Patellar Subluxation and Dislocation*. Philadelphia, WB Saunders Co, 1984, pp 1-198
13. Insell J: Chondromalacia patellae: Patellar malalignment syndrome. *Orthop Clin North Am* 10: 117-127, 1979
14. Kessler RIM, Hertling D: *Management of Common Musculoskeletal Disorders: Physical Therapy Principles and Methods*. Philadelphia, Harper & Row, 1983, pp 394-447
15. Laurin CA, Dussault R, Levesque HP: The tangential X-ray investigation of the patellofemoral joint: X-ray technique, diagnostic criteria, and their interpretation. *Clin Orthop* 144: 16-26, 1979
16. Laveau BF, Rogers C: Selective training of the vastus medialis muscle using EMG biofeedback. *Phys Ther* 60: 1410-1415, 1980
17. Levine J: Chondromalacia patella. *Physician Sportsmed* 7(8): 41-49, 1979
18. Lieb FJ, Perry J: Quadriceps function: An electromyographic study under isometric conditions. *J Bone Joint Surg* 53A: 749-758, 1971
19. Malek MM, Mangine RE: Patellofemoral pain syndromes: A comprehensive and conservative approach. *J Orthop Sports Phys Ther* 2: 108-116, 1981
20. McConnell J: The management of chondromalacia patellae: A long term solution. *Aust J Physiother* 32: 215-223, 1986
21. Merchant AC, Mercer RL, Jacobsen RH, et al: Roentgenographic analysis of patellofemoral congruence angles. *J Bone Joint Surg* 56A: 1391-1396, 1974
22. Moller BN, Jurik AJ, Tidemand-Dal C, et al: The quadriceps function in patellofemoral disorders: A radiographic and electromyographic study. *Arch Orthop Trauma Surg* 106: 195-198, 1987
23. Radin EL: The physiology and degeneration of joints. *Semin Arthritis Rheum* 2: 245-257, 1973
24. Schmid FR, Ogata RI: The composition and examination of synovial fluid. *J Prosthet Dent* 18: 449-457, 1967
25. Steadman JR: Nonoperative measures for patellofemoral problems. *Am J Sports Med* 7: 374-375, 1979
26. Wright V, Dowson D, Saller PC: Bio-engineering aspects of synovial fluid and cartilage. *Mod Trends Rheumatol* 2: 21-29, 1971