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Disclosures:
Financial disclosure statements have been obtained, and no conflicts of interest have been reported by the authors or by any individuals in control of the content of this article.

0894-9115/12/9102-0098/0
American Journal of Physical Medicine & Rehabilitation

DOI: 10.1097/PHM.0b013e318228c505

ORIGINAL RESEARCH ARTICLE

The Effects of Quadriceps Strengthening on Pain, Function, and Patellofemoral Joint Contact Area in Persons with Patellofemoral Pain

ABSTRACT

Chiu JKW, Wong Y-m, Yung PSH, Ng GYF: The effects of quadriceps strengthening on pain, function, and patellofemoral joint contact area in persons with patellofemoral pain. Am J Phys Med Rehabil 2012;91:98–106.

Objective: Patellar malalignment is a major cause of patellofemoral pain syndrome (PFPS), but the relationship between clinical symptoms and changes in patellar position and knee muscle strength has not been confirmed. This study examined the effect of weight training on hip and knee muscle strength, patellofemoral joint contact area, and patellar tilt on subjects with and without PFPS, hoping to develop an optimal rehabilitation protocol for subjects with PFPS.

Design: The study uses a prospective independent group comparison. Fifteen subjects with and without PFPS were assessed for knee strength, patellofemoral joint contact area, and patellar tilt angle using magnetic resonance imaging. The subjects with PFPS were also examined and given a numeric pain rating score and a Kujala patellofemoral score. The subjects performed lower-limb weight training 3 times/wk for 8 wks, and the outcomes were assessed both before and after training.

Results: Subjects with PFPS have increased their patellofemoral joint contact area after weight training ($P < 0.001$). No statistical significant change was found on the patellar tilt angle. The isometric and isokinetic knee strength in subjects with and without PFPS have increased after weight training (P value increased from 0.007 to 0.05). Both numeric pain rating and Kujala patellofemoral score in the PFPS group improved after training ($P < 0.001$).

Conclusions: Weight-training exercise increased knee muscle strength and the patellofemoral joint contact area, which could reduce mechanical stress in the joint, improving pain and function in subjects with PFPS.

Key Words: Knee, Joint Contact, Patellar Tilt Angle, Muscle Strengthening, Magnetic Resonance Imaging

Patellofemoral pain syndrome (PFPS) is a collective term describing the diffuse pain conditions in the anterior compartment of the knee and is one of the most common musculoskeletal problems seen in people with high levels of physical activity.[1] Different etiologies have been proposed for PFPS, including lateral patella malalignment,[2] abnormal patellar tracking, and decreased patellofemoral joint contact area such as in patella alta.[3] The abnormal patellar position and maltracking could be caused by imbalanced muscle pull on the patella,[4] underdeveloped bony configuration of the distal femur, or weakness of the vastus medialis obliquus (VMO), leading to excessive lateral tracking of patella.[5]

Wong and Ng[2] have studied the relationship between patellar mobility with the bony geometry of knee and found that lesser inclination of the lateral femoral groove was associated with higher passive patellar mobility. When the passive stability of patella decreased, dynamic stability would play an essential role. Amed et al.[6] reported that a lateral shift of 5 mm of patella was correlated with a 50% decrease in VMO activity. VMO is a patellar stabilizer, and the weakening of this muscle has been reported to be a predisposing factor of PFPS.[7] The abnormal position and maltracking of patella could be caused by imbalanced muscle pull-on patella,[8] underdeveloped bony configuration of the distal femur, or weakness of VMO, leading to excessive lateral tracking of the patella.[7]

The usual management for PFPS is done through conservative treatment.[9] Physical exercises have long been reported to be effective in strengthening the muscles and soft tissues.[10] It has also been reported that a supervised physical therapy program could reduce pain and improve functions in patients with PFPS.[11] Retraining of the VMO and general quadriceps strengthening could improve both quadriceps strength and electromyography onset timing of VMO and vastus lateralis activity.[12] Both open and closed kinetic chain exercises have been demonstrated to improve knee function and long-term pain reduction for people with PFPS.[13,14] Furthermore, subjects with chronic PFPS were found to achieve marked functional improvement after undergoing 8 wks of physical exercise.[9]

However, the mechanism of pain reduction was not well investigated in previous studies. Powers et al.[15] studied the effect of bracing and reported a marked reduction in pain and an increase in contact area with the use of bracing, but there was little change in patellar alignment. Because joint stress is defined as the force per unit area, increase in contact area would lower the stress; therefore, a possible means to reduce pain is by increasing the joint contact area.[15] However, bracing is a passive means of controlling patellar shift without active muscle involvement. Conflicting results that subjects with PFPS were found to have an increase in total contact area compared with those without PFPS at 15-degree flexion and that no migration of contact area was observed between 15 degrees and 30 degrees of knee flexion were reported by others.[16]

In a study using a feline model, it was proposed that the increase in the contact area of the patellofemoral joint could regulate the pressure on the cartilage during activities such as jumping and running, in which the loading to the patellofemoral joint would be larger. Therefore, a training program that might increase bony contact area was advocated so as to lower joint stress.[17]

A recent study has found that an 8-week weight-training program was effective in attenuating the predisposing factors of PFPS and in strengthening the patellar stabilizers for previously untrained subjects.[10] After weight training, the VMO muscle was hypertrophied, the lateral patellar shift was reduced, and knee extension strength was increased. However, the effect of exercise training on the biomechanical functioning of the patellofemoral joint was not studied. Connolly et al.[16] measured the cartilage contact area of the patellofemoral joint during isometric loading condition and found an increase in joint contact area in subjects with PFPS at low knee-flexion angle. They suggested that it was possibly a compensation mechanism to redistribute patellofemoral load and stress.[16] Hitherto, there is no report on the effects of weight training on the patellofemoral joint contact area, and this is important in determining joint stress. Therefore, the objective of this study was to investigate the effect of weight training on the patellofemoral joint contact area and lower-limb muscle strength on subjects with and without PFPS.

We hypothesized (1) that subjects with PFPS would benefit more from the exercises by increasing the muscle strength and patellofemoral joint contact area and patellar tilt angle than would able-bodied subjects and (2) that pain and knee function in subjects with PFPS would improve after the exercise training program.

METHODS

Subjects

Nine subjects (five women, four men) diagnosed with PFPS and six able-bodied subjects (three women, three men) aged between 18 and 45 yrs were recruited for the study. The subjects were divided into the PFPS (n = 9) and healthy subject (n = 6) groups.

The subjects in the PFPS group were examined by their attending physicians and were referred for rehabilitation. The criteria for diagnosis were that the subjects have an insidious onset of symptoms aggravated by walking stairs, deep squatting, kneeling, prolonged sitting in a knee-bending position, and standing up from sitting.[18] Subjects were excluded if they have engaged in regular weight training or in a knee rehabilitation program, if they have clinical signs of lower-limb joint degeneration or back pain within 6 mos before the study, or if they were on analgesics during the study. This study was reviewed and approved by the Human Subjects Ethics Review Committee of the administrating institute, and all subjects gave their written informed consent before joining the study.

All subjects were measured before and after the training program that lasted for 8 wks. All measurements were performed by a physical therapist who has more than 10 yrs of experience in musculoskeletal assessments.

Intervention

Subjects in both groups received supervised exercise training three times a week for 8 wks. All the training sessions were supervised by a physical therapist experienced in the physical conditioning program. The intensity of training for the PFPS group was adjusted for each subject so that their symptoms would not be aggravated during the exercise.

Before each training session, the subjects performed standardized stretching for the quadriceps, hamstrings, and gluteal and calf muscles. The exercise program included "leg press" on a machine (Tuff Stuff, Pomona, CA) and "knee extension exercise" on a weight machine (Apollo 350; Tuff Stuff, Pomona, CA). Each exercise involved four sets of ten repetitions with a 1-min rest between sessions. The resistance of the exercise was based on ten repetitions maximum, which was determined in the first training session and the ten-repetition maximum load was adjusted regularly during the period of study. All training sessions were conducted by the same physical therapist on each subject on an individual basis.

Outcome Measures

Knee Muscle Strength

The knee muscle strength was measured using an isokinetic dynamometer (Cybex Norm; Cybex International Inc., Ronkonkoma, NY). The subjects were in a sitting position on the isokinetic test bench with the hip at 85-degree and the knee at 90-degree flexion. The subjects performed five repetitions of submaximal isometric knee extension to acquaint themselves with the procedures before the real test. The test lasted for 4 secs and was repeated three times with a 2-min rest between each session. The mean value of the three trials was used for analysis.

After isometric testing, the subjects proceeded with the isokinetic testing. They performed two sets of five repetitions of isokinetic full-range knee flexion/extension at an angular speed of 120 degrees/sec[19] with maximal effort. The mean of the five repetitions of each set was calculated, and the higher value of the two means was used for analysis.

Patellofemoral Joint Contact Area

The patellofemoral joint contact area was measured with magnetic resonance imaging (MRI). Subjects were either tested in a hospital or at a private MRI clinic. The machine in the hospital was a 1.5-T MRI scanner in conjunction with surface coils (Magnetom Avanto; Siemens AG, Erlangen, Germany) to record axial T1-weighted images within the following parameters: repetition time (TR), 420 msecs; echo time (TE), 50 msecs; number of excitations (NEX), 1; matrix size, 512 $\times$ 512; field of view, 20 $\times$ 20 cm; and chemically selective fat suppression, slice thickness of 1 mm. The machine in the private clinic was a 3.0-T MRI scanner with fast spoiled gradient echo sequence (MR-Signa Excite HD; GE, General Electric Company, USA) to record TE, 2.5 msecs; NEX, 0.8; matrix size, 512 $\times$ 512; field of view, 24 $\times$ 24 cm; and chemically selective fat suppression, slice thickness of 1 mm to capture the images.

The subjects were placed in a supine position, lying with a wooden block supporting the back of their knees so as to maintain the joints at 40-degree flexion when the quadriceps was relaxed (Fig. 1). Immediately before scanning, the subject was asked to extend the knee so that the big toe could touch the base of a plastic block preplaced inside the scanner.[10] When the big toe just touched the plastic block, the knee would be at 20 degrees of flexion. Scanning would then be started, and the subject was asked to stay in that position steadily throughout the 90 secs of scanning. The reason for asking the subjects to touch the plastic block with their big toe was to standardize the level of quadriceps contraction so that the scanning could reveal the contact area of the patellofemoral joint under a standardized pulling force of the quadriceps on patella.

FIGURE 1 *Positioning of patient for MRI. The subject is required to extend to knee to 20-degree flexion with the big toe touching the plastic board. MRI indicates magnetic resonance imaging.*

Image datasets collected were saved in DICOM format for offline analysis. The MRI sequence axial images were analyzed using ImageJ software (ImageJ Version 1.42q; Wayne Rasband, National Institutes of Health, USA) to determine the patellofemoral joint contact area. The joint contact on each magnetic resonance image is defined as the region that no distinct separation could be identified between patella and femur. A curvilinear line of contact between the patella and femur was drawn and then measured on each image. The length of contact on each magnetic resonance image was multiplied by the 1-mm slice thickness to yield an intraslice contact area. The areas of contact from sequential magnetic resonance images were summated to obtain a total patellofemoral joint contact area. All contact area measurements were reported in square millimeters. This measuring method has been found to be reliable and comparable (intraclass correlation coefficient [ICC] > 0.91) with measurements obtained from pressure-sensitive film in human cadaveric specimens.[20] Good interrater reliability (ICC = 0.78) was found in the current study. All radiographic measurements were then done by a trained investigator who was blinded to the subjects' information. Three measurements were recorded and then averaged for final analysis.

Patellar Tilt Angle

Patellar tilt angle measurements were performed according to the method described by Powers et al.[21] Patellar tilt angle is the angle formed by a line joining the maximum width of the patella and a line tangent of the posterior femoral condyles. The measurement is a reliable method to detect the changes of patellar tilt in relation to the femur (ICC(2,1) = 0.85).[22]

Pain and Functional Measurement

A chart presenting a numeric pain rating scale covering a range from 0 to 10, with the phrase "No pain" on the left and "Worst imaginable pain" on the right, was shown to the subjects in the PFPS group. The subjects were asked to rate their worst level of pain experienced during the last 24 hrs on the numeric pain rating scale.[23]

The Kujala Patellofemoral Score (KPS) was administered for the PFPS Group. It is a 13-item questionnaire that includes questions on pain and functional activities. Each item is weighted, and the scores are summated to provide an overall score ranging from 0 to 100, with higher scores representing less disability.[24] The KPS has been demonstrated to possess high test-retest reliability with an ICC of 0.95, and the minimal clinically important difference for the scores was reported to be between 10 and 13 points.[24]

Statistical Analysis

All statistical analyses were performed using SPSS statistical software, version 16 (SPSS Inc., Chicago, IL). Independent sample *t* test was used for the baseline comparisons of age, body weight, and height. Paired *t* test was used to compare the within-group pretraining and posttraining isometric, isokinetic knee extensor strength, patellofemoral joint contact area, and patellar tilt angle. The pretraining and posttraining numeric pain rating scale scores and Kujala patellofemoral score in the PFPS group were also compared using the paired *t* test. Intratester reliability of the patellofemoral joint contact area measurement was performed by repeating the measurements of five magnetic resonance images the

TABLE 1 Demographic data of the subjects

	HS Group (n = 6), mean ± SD	PFPS Group (n = 9), mean ± SD
Female/male ratio	3:3	5:4
Age, yrs	31.83 ± 8.57	34.33 ± 9.75
Body weight, kg	54.73 ± 10.78	64.40 ± 13.04
Height, cm	161.00 ± 15.56	167.00 ± 8.57

PFPS, patellofemoral pain syndrome; HS, healthy subject.

next day after the initial measurement. The rater was blinded to the readings of the initial measurements. The standard error of measurement was determined, and the minimal detectable change of the contact area was found.[25] The level of significance was set at 0.05 for all tests.

RESULTS

Table 1 shows the demographic data of all the subjects. There was no significant difference among the groups in age, body weight, and height at baseline measurements.

For the four dependent variables of isometric knee extension strength, isokinetic knee extension strength, patellofemoral joint contact area and patella tilt angle, there was no statistically significant difference between the baseline values of the two groups (Table 2).

The mean patellofemoral joint contact area among the male subjects is 269.62 + 85.17 mm^2, whereas that for the female subjects is 198.63 + 67.87 mm^2 (P = 0.47). In the PFPS group, the mean contact area of the men and women is 196.08 + 70.63 mm^2 and 180.51 + 39.03 mm^2, respectively (P = 0.073) (Figs. 2*A*–*B*). The ICC(3,1) was 0.95. The 95% confidence intervals of the contact area measurements pretraining and posttraining were 178.55 to 248.99 and 205.03 to 331.00 mm^2, respectively. The minimal detectable change measurement of contact area was 11.34 mm^2.

After the 8 wks of training, significant improvements were found in all outcome measures except for the patella tilt angle in the PFPS groups (P values range from <0.001 to 0.5; Table 2; Figs. 3–5). No statistically significant differences in any outcome measures were found in the healthy subject group, although posttraining data showed improvement

TABLE 2 Baseline and postexercise comparison of knee strength, PFJ contact areas, and patellar tilt angle

	HS Group (n = 6)	PFPS Group (n = 9)	Between-Groups Difference (P)
Isometric knee extension strength, nm			
Baseline	80.5 ± 25.12	58.44 ± 20.77	0.09
Posttraining	105.83 ± 35.19	80.89 ± 23.01	0.12
P	0.18	0.045[a]	
Pre/post difference	25.33 ± 12.24	22.44 ± 5.61	0.54
Isokinetic knee extension strength, nm			
Baseline	29.5 ± 10.77	22.56 ± 7.99	0.17
Posttraining	42.33 ± 15.15	31.89 ± 10.90	0.14
P	0.12	0.05[a]	
Pre/post difference	12.83 ± 5.15	9.33 ± 4.61	0.19
Patellofemoral joint contact area, mm^2			
Baseline	217.65 ± 75.24	187.43 ± 51.96	0.37
Posttraining	234.95 ± 75.79	246.32 ± 48.02	0.73
P	0.17	0.00[a]	
Pre/post difference	17.30 ± 26.77	58.89 ± 17.53	0.00[a]
Patella tilt angle, degrees			
Baseline	16.17 ± 6.52	16.61 ± 7.52	0.91
Posttraining	19.33 ± 6.15	17.56 ± 7.62	0.64
P	0.06	0.71	—
Pre/post difference	3.16 ± 3.22	0.94 ± 7.41	0.50

[a]Significant difference between groups with P < 0.05.

PFJ, patellofemoral joint; PFPS, patellofemoral pain syndrome; HS, healthy subject.

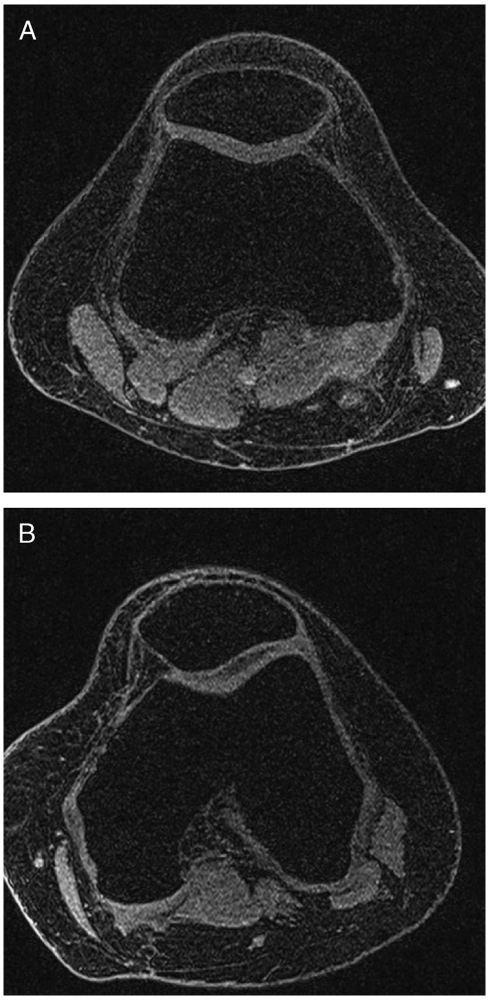

FIGURE 2 *MRI image of patellofemoral joint. A, A typical image from a healthy subject with both the medial and lateral facets touching the femoral condyles in congruent. B, A typical image from a PFPS subject showing the malalignment of patella, with only the lateral facet touching the femoral condyles. MRI indicates magnetic resonance imaging.*

trends. When sex difference was taken into consideration, it was found that there was significant difference after training in the PFPS group ($P < 0.01$), with men showing more improvement than women.

Pain and KPS

The mean numeric pain rating scale of the PFPS group was found to have significantly reduced from 6.8 ± 0.67 to 2.8 ± 1.64 ($P < 0.001$) after training. The posttraining mean KPS in the PFPS group was 70.6 ± 5.46, which was significantly higher than the pretraining mean of 83.8 ± 7.01 ($P < 0.001$).

DISCUSSION

A significant reduction of pain was found in the PFPS group, from 6.8 ± 0.67 at baseline to 2.8 ± 1.64 ($P < 0.001$) after the training program. The magnitude of improvement is substantial as the clinically meaningful improvement has been reported to be 1.2 to 2.0 points in subjects with PFPS.[23,26] Besides reduction in pain, there was a significant improvement in KPS in these subjects. The value improved from 70.6 ± 5.46 at baseline to 83.8 ± 7.01 ($P < 0.001$) after the training program. The large drop in pain level and improvement in knee functional scores are strong clinical indicators of the effectiveness of the weight-training program for people with PFPS.

The present results supported the first hypothesis that muscle strength in the PFPS group would demonstrate a significant increase after the weight-training program ($P < 0.001$). The patellofemoral joint contact areas of both groups had increased in line with knee and hip strength, and it was statistically significant in the PFPS group ($P < 0.001$). It is postulated that the increase in the muscle strength of quadriceps and hip muscles in the PFPS group could have contributed to the increase in patellofemoral joint contact area after the weight-training program, possibly because of the change in patella position by the quadriceps muscle.

The current exercise strengthened the quadriceps muscle by both open and closed kinetic chain movements. Felicio et al.[27] supported the hypothesis that patellar stability could possibly increase during voluntary isometric contraction at 30 and

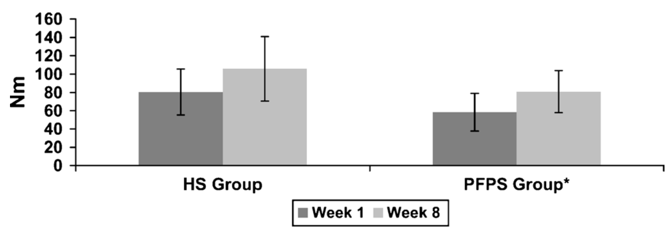

FIGURE 3 *Isometric knee extensor strength across time (mean ± SD). PFPS indicates patellofemoral pain syndrome; HS, healthy subject.* indicates significant differences within the group (P = 0.045).*

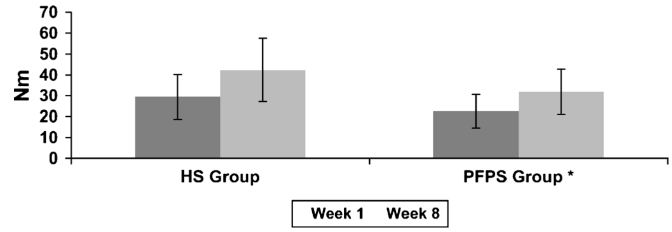

FIGURE 4 *Isokinetic knee extensor strength across time (mean ± SD). PFPS, patellofemoral pain syndrome; HS, healthy subject. * indicates significant differences within the group (P = 0.05).*

45 degrees of knee flexion in either open or closed kinetic chain. A more balanced initial quadriceps activation could be promoted through closed kinetic chain exercise.[28]

Our findings are in agreement with a recent report that resistance training could strengthen VMO and reduce lateral patellar tracking in postural loading and dynamic actions.[10] There are different views that VMO would effectively stabilize patella in extension because the patellar position was not found to change significantly through quadriceps contraction.[29] However, that study has not evaluated the effect of VMO on the patellofemoral joint after rehabilitation because the muscle strength of VMO would be stronger after training and because the periarticular soft tissue tension might have also changed. The present study demonstrates that the quadriceps strength in subjects with PFPS has increased after the strength training, which would benefit the patellofemoral joint because it has been reported that strong knee extensor muscles could induce more favorable patellar tracking and joint stability.[10]

From a mechanical point of view, it is expected that quadriceps contraction would increase the compression of patella on the trochlear surface. A previous study has shown that patellofemoral joint contact area would increase with knee flexion and that quadriceps contraction had little effect on the joint contact area during upright weight-bearing conditions,[30] but a more recent study has found that patella was displaced proximally when the quadriceps contracted during weight bearing, thus altering the joint contact area.[31] However, these studies had only included healthy subjects who did not have the problem of PFPS; hence, the role of quadriceps contraction in subjects with PFPS has not been well studied. It is possible that, because of pain and other pathologic changes in PFPS, the biomechanics of the patellofemoral joint is altered, and the role of quadriceps may be different. The increase in the patellofemoral joint contact area in subjects with PFPS could be caused by the repositioning of patella in the trochlear groove or by the deformation of the cartilage upon loading, which has been reported in studies with the feline model.[17]

Our results did not demonstrate a significant difference in muscle strength in the healthy weight training and control groups. A previous study by Wong et al.[10] has revealed that hip and knee muscle strength in healthy individuals would increase after 8 wks of strength training. The difference in sample size may account for the discrepancy because there were only six healthy subjects in the weight-training group in this study, which has rendered insufficient power (only 0.2) to detect change in this parameter.

The PFPS group was found to have 13.9% less patellofemoral contact area than the other group before training (Table 2). Previous studies have reported that patellofemoral contact areas in subjects with patella alta was reduced[26] and that they also had more lateral patellar displacement and tilting. Unfortunately, we only tested a single knee flexion angle of 20 degrees, and the result from a

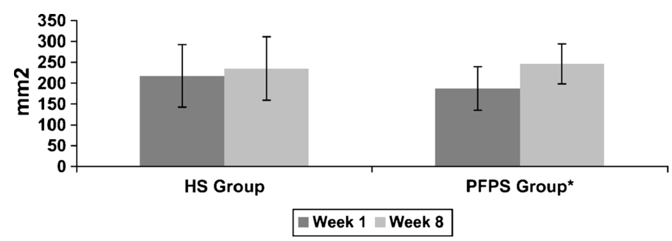

FIGURE 5 *PFJ contact area across time (mean ± SD). PFJ indicates patellofemoral joint; PFPS, patellofemoral pain syndrome; HS, healthy subject. * indicates significant difference (P < 0.001).*

single angle is not conclusive to reveal the etiology of PFPS. Future studies should aim to study the contact area at a range of movement so that the patellar height can be taken into consideration in the measurement.

Nearly half of the patients with PFPS have recurrent subluxation or maltracking of patella, including excessive lateral translation and tilting,[11] during knee movements. Such a malaligned patella has been reported to alter the patellofemoral contact area causing joint stress,[32] which may partially explain the causal relationship between the patellofemoral malalignment with joint stress and pain.[33] However, there was no significant change in the patellar tilt found in the current study. The increase in the contact area is possibly caused by other factors such as the proximal muscles at the hip because it was reported that the weakness of quadriceps and hip muscles would lead to abnormal rotation of femur and patellar malalignment.[34] It is therefore recommended that hip muscles should be considered in the model of future studies on patellofemoral joint contact area.

Salsich and Perman[35] revealed that tibiofemoral rotation would lead to changes in the patellofemoral joint contact areas, whereas the patella tilt angle was not associated with predictable changes in the contact area in subjects with and without PFPS.[35] It was suggested that improvement in pain and increase in patellofemoral joint contact area might not be in line with changes in patellar alignment in terms of patella tilt angle.[15]

Limitation of the Study

The contact area of the patellofemoral joint was assessed against the weight of the subjects' own legs rather than the whole body weight. It was a compromised weight-bearing examination because of the limitation that the MRI clinics where the assessments were conducted did not have an upright MRI machine. It would have been better if the MRI examination could be done during a real weight-bearing condition to establish a more functional patellofemoral joint contact area of the subjects. Despite this, the study has demonstrated that weight training would lead to clinical improvement for subjects with PFPS, that the long-term effect was not examined, and that the clinical application of our findings should be interpreted with caution. There was no randomization of the PFPS group because of the ethical consideration that makes it difficult to eliminate potential bias of subject selection.

CONCLUSIONS

An 8-wk lower-limb weight-training exercise program can increase the contact area of the patellofemoral joint, which could lower mechanical stress in the joint and reduce pain and improve knee function and muscle strength in subjects with PFPS.

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