

# Effect of leg press training on patellar realignment in patients with patellofemoral pain

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**Abstract.** [Purpose] The purpose of this study was to investigate the effect of leg press and leg press with hip adduction exercise training on patellar alignment and pain in patients with patellofemoral pain (PFP). [Subjects and Methods] Seventeen patients participated in this study. Eight weeks of leg press or leg press with hip adduction training, including progressive lower-limb weight-training and stretching, was given. Patellar alignment (tilt and displacement) and pain measurements were conducted before and after leg press or leg press with hip adduction training. Patellar tilt angle and the bisect offset index were measured on axial computed tomography scans of the fully extended knee position with the quadriceps relaxed and contracted. Pain was assessed by using a 10-cm visual analog scale. [Results] No differences were found in patellar tilt and displacement with the quadriceps either relaxed or contracted after leg press and leg press with hip adduction. However, significant pain reduction was evident in both leg press and leg press with hip adduction. [Conclusion] The results indicated that patellar realignment does not appear to mediate pain alleviation. Furthermore, hip adduction in addition to leg press training had no additive beneficial effect on patellar realignment or pain reduction.

**Key words:** Patella, PFP, Anterior knee pain

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## INTRODUCTION

Patellofemoral pain (PFP) is a common musculoskeletal condition of the knee which is believed to occur because of lateral patellar malalignment<sup>1-5)</sup>. Closed-chain exercises for quadriceps strengthening combined with flexibility exercises for the lower limb musculature have been widely used in PFP treatment<sup>6)</sup>. Despite the clinical effectiveness of the leg press (LP) exercise, which along with lower-limb stretching has been shown to ease pain and promote functional ability<sup>7, 8)</sup>, few studies have looked at the strengthening and stretching exercise's effect on patellar realignment<sup>8)</sup>. Although a recent magnetic resonance imaging study identified increased patellofemoral joint contact area as a potential source of pain reduction<sup>8)</sup>, their results did not indicate any positive effects of strengthening and stretching exercise training on patellar alignment (i.e., patellar tilt angle). Furthermore, there was no mention of the patellar displacement<sup>8)</sup>.

The vastus medialis obliquus (VMO) muscle is an important medial stabilizer of the patella, and it resists the lateral pull of the vastus lateralis (VL)<sup>9)</sup>. An in vitro biomechanical study showed that an insufficient VMO strength can reduce

patellar lateral stability by 30%<sup>10)</sup>. Using a regression model, another in vivo dynamic computed tomography (CT) study indicated the cross-sectional area of the VMO is predictive of patellar tilt<sup>11)</sup>. The role of the VMO is therefore considered important in the rehabilitation of patients with PFP, especially those with an extremely, laterally malaligned patella<sup>11)</sup>.

Resistance training of the quadriceps may possibly influence patellar alignment by altering the sensorimotor control of the vastus muscles or the cross-sectional area of the VMO<sup>12, 13)</sup>. Incorporating hip adduction into LP exercises is another potential way of achieving this<sup>7, 14)</sup>. LP with hip adduction (LPHA) within 45° of knee extension/flexion promoted a greater VMO-to-VL ratio as well as VMO hypertrophy<sup>7, 14)</sup>. It was speculated by the authors that incorporating hip adduction is more likely to realign the patella<sup>7, 14)</sup>. However, to the best of our knowledge, no studies have examined this issue. It remains unclear whether the degree of patellar alignment is mediated by a hip adduction exercise strategy (i.e., LPHA), and if it is, to what extent.

The importance of axial CT for examining the patellofemoral joint is well-established<sup>11, 15-18)</sup>, and the CT gantry is spacious enough for the examination of dynamic movements<sup>11)</sup>. Thus, a dynamic technique could be used to assess the role of the quadriceps in repositioning the patella.

The purposes of this study were to investigate the effects of LP combined with lower-extremity stretching exercises on the patellar alignment in patients with PFP, and to examine the effect of LPHA exercise on patellar alignment. The patellar alignment was assessed by using CT, with the quad-

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riceps both relaxed and contracted to determine whether the exercise intervention changed both the static and dynamic patellar alignment. It is generally assumed that decreased pain is associated with changes in patellar alignment. To clarify the interrelationship between patellar alignment and clinical symptoms, pain severity was also assessed as an outcome of the exercise intervention. It was our hypothesis that both exercises would reduce pain with substantial changes in patellar alignment, but of differing degrees.

## SUBJECTS AND METHODS

Seventeen patients diagnosed with PFP participated in this study. The inclusion criteria were: insidious onset of symptoms unrelated to traumatic accident; the presence of pain for more than 1 month; and experience of anterior or retropatellar knee pain after performing at least 2 of the following activities: prolonged sitting, stair climbing, squatting, running, kneeling, hopping/jumping, and deep knee flexing. In addition, participants had to exhibit at least 2 of the following positive signs of anterior knee pain during the initial physical examination: patellar crepitus; pain following isometric quadriceps contraction against suprapatellar resistance with the knee in slight flexion (Clarke's sign); pain following compression of the patella against the femoral condyle with the knee in full extension (patellar grind test); tenderness upon palpation of the posterior surface of the patella or surrounding structures; and pain following resisted knee extension. Patients were excluded if they had a diagnosis of other knee pathology, a history of patellar subluxation or knee surgery, central or peripheral neurological pathology, lower extremity malalignment (i.e., pronated foot), or severe knee pain (visual analog scale: VAS > 8), or had received nonsteroidal anti-inflammatory drugs, injections, or physical therapy in the preceding 3 months. All subjects were enrolled after providing their written informed consent and the study procedure was approved by the Research Ethics Committee of the National Taiwan University Hospital.

Using numbered opaque envelopes, 9 and 8 participants were randomly assigned to the LP and LPHA intervention groups, respectively. Of these, 6 and 5 patients, respectively,

presented with bilateral symptoms. Thus, a total of 15 and 13 PFP knees were studied in the LP and LPHA groups. There were no significant differences in the basic demographic data between the groups (Table 1).

Patients performed triweekly LP or LPHA exercise three times a week, for a total of 8 weeks, according to the method of Song et al<sup>7)</sup>. Exercises were performed by using an EN-Dynamic Track machine (Enraf-Nonius B.V., Rotterdam, The Netherlands) under a physical therapist's supervision. Patients were unilaterally trained at 60% of 1 repetition maximum for 5 sets of 10 repetitions each. For training resistance advancement, the 1 repetition maximum was remeasured every 2 weeks, and the exercise intensity was adjusted accordingly. In addition, patients were taught to perform static stretching of their quadriceps, hamstring, calf, and iliotibial band muscles. The stretching regimen was supervised. Table 2 summarizes the detailed exercise regimen. The only difference between the LP and LPHA intervention was the resisted hip adduction. For LPHA, patients forcefully pressed their leg with concurrent isometric hip adduction to resist 50 N resistance offered by the blue TheraBand (The Hygenic Corporation, Akron, OH, USA). In the LP group, the TheraBand was only wrapped around each patient's thigh, without resistance, to mimic the tactile received by the LPHA group. During the intervention period, all participants were asked not to perform or receive any other exercise program or intervention.

The pre- and post-training assessment of patellar align-

**Table 1.** Demographic data of the participants

	LP	LPHA
Gender (male:female)	2:7	3:5
Age (years)	40.3 ± 10.5	38.3 ± 11.3
Height (cm)	161.1 ± 7.4	163.9 ± 7.8
Weight (kg)	59.1 ± 10.5	55.5 ± 8.7
Involved side (bilateral:unilateral)	6:3	5:3

Results are shown as mean ± standard deviation.

LP: leg press exercise; LPHA: leg press with hip adduction exercise

**Table 2.** Exercise regimens of LP and LPHA exercises

	Exercise regimen
	1) Hot pack to quadriceps (15 minutes)
	2) LP
	• from 45° of knee flexion to full extension
	• 2-second concentric and eccentric contractions paced by using a metronome
LP exercise	• 60% of 1 RM for 5 sets of 10 repetitions
	• left and right limbs alternatively trained in each exercise set
	• 2-second break between each repetition and a 2-minute break between each set
	3) Self-stretches of quadriceps, hamstrings, iliotibial bands and calf muscle groups (30 seconds × 3 repetitions/ muscle group)
	4) Cold pack to knee joints (10 minutes)
LPHA exercise	Same as LP exercise with the resisted hip adduction added

LP: leg press exercise; LPHA: leg press with hip adduction exercise; RM: repetition maximum

ment and pain were performed within 1 week before and after finishing 8 weeks of exercise intervention by the same physical therapist who was blinded to patient treatment.

All participants underwent axial CT imaging by a Pace General Electric Machine (GE Medical Systems, Milwaukee, WI, USA) of the symptomatic knees, with their quadriceps muscle in relaxation and maximal voluntary isometric contraction for the assessment of patellar alignment. The CT images (5-mm slice thickness) were obtained at full knee extension through the widest diameter of the patella, which facilitated an optimal view of the patellofemoral joint for measurement<sup>11, 17</sup>. Imaging was performed with the subjects in a supine position, with their ankles restrained by using felt strips to prevent leg rotation. A rigid support and soft padding was placed underneath the knees to maintain the desired testing position<sup>11</sup>.

Centricity Radiology RA 600 image software (version 6.1; GE Medical Systems) was used to determine the patellar alignment (i.e., tilt and displacement). The mediolateral tilt of the patella was measured along the patellar tilt angle (PTA), which is the angle formed by the line joining the maximum width of the patella and the line joining the posterior femoral condyles<sup>3, 19</sup>. Mediolateral patellar displacement was assessed by using the bisect offset index (BSO)<sup>3, 19</sup>. The BSO was measured by drawing a line connecting the posterior femoral condyles and then projecting a perpendicular line anteriorly through the deepest point of the trochlear groove. When the trochlear groove was flattened, the perpendicular line was projected from the bisection of the posterior condyle line. This perpendicular line intersected the patellar width line, and the percentage of the patella lateral to the midline was calculated as the BSO<sup>3, 19</sup>. Larger values of PTA and BSO indicated more lateral tilt or displacement of the patella.

The worst pain that subjects experienced in the week before assessment was evaluated by using a 10-cm VAS, where 0 indicated no pain and 10 indicated extreme/maximal perceived pain<sup>20</sup>.

Statistical analysis was performed by using SPSS version 11.0 (SPSS, Inc., Chicago, IL, USA). For comparisons of age, body height, and weight, the independent t-test was performed. The gender and number of afflicted sides (bilat-

eral vs. unilateral) were compared by using the  $\chi^2$  test, with an  $\alpha$  level of 0.05. Three-way mixed analyses of variance (ANOVA) were performed on both PTA and BSO measures with group (LP or LPHA) as between-subject factor and assessment time point (pre- or post-training) and muscle state (quadriceps relaxation or contraction) as the within-subject factors. The VAS pain score was compared between groups and assessment times by performing a 2-way mixed ANOVA. Differences were considered significant when  $p < 0.05$ .

Pilot work was conducted to ascertain the reliability of patellar alignment measurement on the image. Sixteen images were selected randomly for reassessment of patellar alignment 1-week apart. The intraclass correlation coefficient (ICC<sub>(3,1)</sub>) values for between-day test-retest reliability of PTA and BSO measurements were 0.91 and 0.98, respectively, indicating high reproducibility. The standard error of measurement (SEM) was 1.2° for PTA and 2% for BSO. To calculate power and sample size, we used the concept of the smallest real difference (SRD =  $1.96 \times \sqrt{2} \times \text{SEM}$ , with SEM = 1.2° from a pilot test of reliability) for predetermining the smallest measurement change that can be interpreted as a real difference. Using the SRD between pre- and post-training of 3.4° for PTA and assuming a standard deviation of 3° based on previously published data<sup>21</sup>, at least 13 PFP knees per group would attain 80% power at the  $\alpha$  level of 0.05.

## RESULTS

Table 3 summarizes the main outcomes of the patellar alignment measures and VAS pain scores. Both groups were similar with respect to the PTA and BSO at baseline, regardless of the quadriceps state (relaxation or contraction). There were no significant interaction effects or main effects on the PTA or BSO (Table 4), indicating there were no significant intra- or inter-group differences in patellar alignment following the exercise interventions with the quadriceps either relaxed or contracted. As for pain, no group-by-time interaction was identified with respect to the VAS pain score ( $F = 0.198$ ,  $p = 0.66$ ). Statistically significant reductions in pain were found in both groups after the intervention ( $F = 14.286$ ,  $p < 0.01$ ). The mean decrease of the VAS pain score was

**Table 3.** Comparison of pre- and post-training changes in patellar alignment and pain in the LP and LPHA groups

	LP (n = 15)		LPHA (n = 13)	
	Pre-training	Post-training	Pre-training	Post-training
PTA (°)				
Without contraction	17.4 ± 4.7	17.6 ± 5.4	19.2 ± 2.4	18.9 ± 3.6
With contraction	17.8 ± 5.5	17.6 ± 6.4	18.7 ± 4.5	18.3 ± 4.7
BSO (%)				
Without contraction	63.9 ± 12.2	64.7 ± 8.4	66.4 ± 12.9	66.4 ± 13.5
With contraction	67.0 ± 14.6	68.9 ± 13.9	68.7 ± 15.8	68.9 ± 12.6
VAS pain score (cm)	4.65 ± 2.18	2.25 ± 2.36	4.55 ± 1.90	2.65 ± 2.04

Results are shown as mean ± standard deviation.

LP: leg press exercise; LPHA: leg press with hip adduction exercise; PTA: patellar tilt angle; BSO: bisect offset index; VAS: visual analog scale

2.4 and 1.9 for the LP and LPHA groups, respectively. The degree of pain reduction, however, was not significantly different between the groups ( $F = 0.072$ ,  $p = 0.79$ ) (Table 3).

## DISCUSSION

Quadriceps strengthening together with lower-extremity stretching exercises is one of the most common therapeutic approaches for clinically treating PFP clinically<sup>6, 22</sup>. Consistent with a previous systematic review<sup>6</sup>, our study provides further evidence of the effectiveness of therapeutic exercise in the reduction of pain. Both the LP and LPHA exercise interventions for 8 weeks were found to significantly reduce PFP, but this occurred in the absence of significant changes in patellar alignment. Furthermore, hip adduction had no added effect on patellar realignment or pain relief. Despite the fact that patellar malalignment is thought to contribute to PFP<sup>1-5</sup>, our findings are in agreement with a recent report that weight-training exercise did not change the patellar tilt angle<sup>8</sup>.

Imaging techniques are clinically helpful in the diagnosis of patellar malalignment associated with PFP<sup>3, 19</sup>. The PTA and BSO measured in this study similar in magnitude to the values reported by previous studies<sup>8, 13, 19, 23</sup>. Using imaging techniques to explore the effect of exercise on patellar alignment, an early radiographic study had examined the effects of individualized and progressive therapeutic exercises on patellar alignment at 30° of knee flexion in patients with PFP<sup>24</sup>. The findings revealed that patients who were pain-free after exercises demonstrated significant mean decreases in patellofemoral congruence angles, but not in the patellofemoral index (an indicator of patellar tilt). The decrease in the congruence angle indicated medial tracking of the patella. It is noteworthy that the patients in that study exhibited a mean congruence angle of 8.03° before training, leaving high scope for improvement in patellar displacement. It is difficult to compare our findings with those of the cited studies mentioned, because the manner of exercise,

imaging techniques, indices chosen for assessing patellar alignment, and knee flexion angle tested were different. However, it also appears that patients who have a certain patellar malalignment type may respond differently to exercise intervention. Further studies with larger sample sizes are needed to address this possibility.

Quadriceps contraction plays an important role in mediating the patellar alignment during full knee extension, when the patella is less stable<sup>15, 25</sup>. In the present study, quadriceps contraction had no influence on lateral patellar tilt and displacement. This finding is similar to the conclusions of previous studies that found no difference in lateral patellar tilt or displacement between quadriceps states in extended knee positions<sup>11, 15, 17</sup>. Another study also indicated there was a significant and proportional relationship between the CT measurement of the lateral patellofemoral angle and lateral patellar shift during quadriceps contraction or relaxation at either 0° or 20° of knee flexion ( $r = 0.93-0.96$ ,  $p < 0.01$ )<sup>16</sup>. Conversely, some investigators have reported that quadriceps contraction results in increased patellar lateralization or lateral tilt<sup>11, 18, 23, 26</sup>. Hence, at the present time, there is no consensus about the effect of quadriceps contraction on patellar alignment<sup>26</sup>.

The LP exercise in the current study was designed to strengthen the quadriceps. Resistant hip adduction (LPHA) was additionally performed to specifically target the VMO, because VMO dysfunction is manifest in patients with PFP<sup>27</sup>. The effects of the 2 interventions were comparable, indicating that there is no additive beneficial effect of incorporating hip adduction into the LP exercise, at least with regarding to patellar alignment. The same held true for muscle morphology. Adding isometric hip adduction to the LP exercise did not elicit more VMO hypertrophy than did LP alone<sup>7</sup>, although it is possible that the simple LP exercise simultaneously activates the hip adductor magnus and longus muscles as well as the knee extensor<sup>28</sup>. It should be noted that the hip adduction load was fixed (i.e., 50 N) in the present study, and VMO activation may vary with differ-

**Table 4.** Insignificant main and interaction effects from the 3-way analyses of variance (group by time by muscle<sup>a</sup>) performed on the PTA and BSO

Source	PTA			BSO		
	Sum of squares	df	Mean square	Sum of squares	df	Mean square
Time	0.812	1	0.812	0.001	1	0.001
Time by group	1.014	1	1.014	0.001	1	0.001
Error (time)	193.235	26	7.432	0.193	26	0.007
Muscle	0.862	1	0.862	0.025	1	0.025
Muscle by group	3.662	1	3.662	0.001	1	0.001
Error (muscle)	426.478	26	16.403	0.251	26	0.010
Time by muscle	0.445	1	0.445	0.000	1	0.000
Time by muscle by group	0.179	1	0.179	0.000	1	0.000
Error (time by muscle)	76.932	26	2.959	0.130	26	0.005
Group	37.767	1	37.767	0.006	1	0.006
Error	1,750.454	26	67.325	1.208	26	0.046

PTA: patellar tilt angle; BSO: bisect offset index; df: degrees of freedom

<sup>a</sup>Group refers to leg press exercise/leg press with hip adduction exercise; time refers to pre-/post-training; and muscle refers to quadriceps relaxation/contraction.

ent levels of hip adduction load<sup>29</sup>). On the other hand, squat exercise with hip adduction offers an alternative method of strengthening the VMO<sup>29, 30</sup>.

Although no significant changes in patellar alignment were detected following both exercises, clinically significant pain reductions (>1.5 points on the 10-cm VAS)<sup>20</sup> were detected in both groups. This finding is in accordance with that from a patellar bracing study conducted by Powers et al.<sup>19</sup>, who reported large decreases in pain without obvious changes in patellar alignment. We speculate that the decrease in pain detected in our patient cohort was probably the result of increased quadriceps muscle strength and enhanced flexibility of the soft tissue surrounding the knee<sup>7, 31, 32</sup>. It is likely that quadriceps strength and patellofemoral joint contact area were altered by the exercise intervention, leading to redistributing joint contact pressure, and that pain was decreased as a consequence<sup>8</sup>). Furthermore, it is known that PFP is a chronic pain condition in which central pain mechanisms may be important<sup>33, 34</sup>). Hence, the repeated and rhythmic LP training and lower-extremity stretching (as a form of proprioceptive input), the patients' belief in treatment or therapist, and accompanying cognitive or illness behavior changes (through psychophysiological mechanism) may evoke neuroplastic changes in the central nervous system, and consequently, alter the pain<sup>34</sup>). However, this hypothesis remains unproven.

Our study had several limitations. Lateral patellar tilt and displacement were assessed only in the fully extended knee position, and patellar alignment may exhibit changes at different knee flexion angles. Future studies should examine patellar alignment changes during dynamic tasks and during weight-bearing movements, because femoral motion may influence the patellofemoral kinematics<sup>4</sup>). Our patient population was fairly small. It would be of interest to ascertain whether patients with different types of malalignment (e.g., lateral displacement alone, lateral tilt alone, or a combination of both) would show different responses in terms of patellar movement in response to therapeutic exercise training. Such classifications may facilitate the clinical management of PFP in a more selective manner. Furthermore, because hip external rotator and abductor muscle strengthening exercises are effective in PFP management<sup>35</sup>), future studies should examine their biomechanical influences on patellar alignment.

In conclusion, although LP and LPHA exercises were both effective at reducing PFP, neither of them were beneficial for realignment of the patella. The results indicated that patellar realignment does not appear to mediate pain alleviation, since adding hip adduction to LP had no more beneficial effect on patellar realignment or pain reduction than LP exercise alone.

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