

Prospective comparative study between knee alignment-oriented static and dynamic balance exercise in patellofemoral pain syndrome patients with dynamic knee valgus

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Abstract

Exercise therapy has been reported as an effective treatment method for patellofemoral pain syndrome (PFPS). However, there is a lack of studies regarding the effectiveness of balance exercise in the treatment of patients with PFPS. This study aimed to prospectively compare changes in proprioception, neuromuscular control, knee muscle strength, and patient-reported outcomes between patients with PFPS treated with knee alignment-oriented static balance exercise (SBE) and dynamic balance exercise (DBE). The participants were divided into 2 groups: 17 knee alignment-oriented SBE group and 19 knee alignment-oriented DBE group. Proprioception was assessed by dynamic postural stability using postural stabilometry. Neuromuscular control and knee muscle strength were measured for acceleration time and peak torque in quadriceps muscle using an isokinetic device. Patient-reported outcomes were evaluated using a visual analog scale for pain and the Kujala Anterior Knee Pain Scale. There was greater improvement in dynamic postural stability (0.9 ± 0.3 vs 1.2 ± 0.5 ; 95% confidence interval [CI]: 0, 0.6; Effect size: 0.72; $P = .021$) and quadriceps AT (40.5 ± 14.3 vs 54.1 ± 16.9 ; 95% CI: 2.9, 24.2; Effect size: 0.86; $P = .014$) in the DBE group compared to the SBE group. Knee alignment-oriented DBE can be more effective in improving dynamic postural stability and quadriceps muscle reaction time compared with the knee alignment-oriented SBE in PFPS patients with dynamic knee valgus.

Abbreviations: AKPS = Kujala Anterior Knee Pain Scale, AT = acceleration time, DBE = dynamic balance exercise, ICCs = intraclass correlation coefficients, PFPS = patellofemoral pain syndrome, SBE = static balance exercise, VAS = visual analog scale.

Keywords: balance exercise, dynamic balance, neuromuscular control, patellofemoral pain syndrome, proprioception, static balance

1. Introduction

Patellofemoral pain syndrome (PFPS) is the most common cause of anterior knee pain, resulting from various factors^[1–3] such as quadriceps weakness, knee muscle imbalance, altered lower extremity biomechanics, weakness of gluteal muscles, loss of proprioception, and poor neuromuscular control. Among these factors, the assessment and treatment for impaired proprioception and neuromuscular control were reported as important elements in PFPS patients,^[1,4] as they have been found to be associated with altered lower extremity biomechanics (dynamic knee valgus).^[1,5–8] Clinicians and therapists measure postural stability and muscle reaction time to identify loss of proprioception and neuromuscular control.^[9]

Several previous studies have reported poor postural stability in PFPS patients, thus exercise therapy has been considered in the treatment of these patients.^[10–14] Postural stability consists of static and dynamic balance.^[15–17] In particular, good postural stability may be closely associated with neuromuscular control,^[18–20] hence balance exercises play a significant role in the recovery of proprioception and neuromuscular control.^[18,21,22] Balance exercise is to improve the ability to control and stabilize body position in static and dynamic activities,^[23] and consists of static balance exercise (SBE) and dynamic balance exercise (DBE). SBE can improve the static joint stability within the limits of the base of support, whereas DBE can improve the dynamic joint stability while changing the base of support.^[23,24] Since SBE and DBE can improve the joint stability, it is expected

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that they are beneficial in improving proprioception and neuromuscular control in patients with PFPS.

To date, however, no studies have investigated whether proprioception and neuromuscular control improve after balance exercises in patients with PFPS, especially in static balance and dynamic balance exercises. Furthermore, several studies have reported on improvements in clinical outcomes in terms of muscle strength, proprioception, and pain after specific muscle-targeted exercises such as quadriceps and gluteal muscles in patients with PFPS.^[25-27] However, no studies have examined proprioception, neuromuscular control, knee muscle strength, and patient-reported outcomes (including the visual analog scales [VAS] and the Kujala Anterior Knee Pain Scale [AKPS]) after knee alignment-oriented SBE and DBE.

This study aimed to prospectively compare changes in proprioception (dynamic postural stability), neuromuscular control (acceleration time), knee muscle strength (quadriceps strength), and patient-reported outcomes (VAS and AKPS) between PFPS patients with dynamic valgus knee treated with knee alignment-oriented SBE and DBE. It was hypothesized that there would be more improvement in all parameters in the DBE group, compared to the SBE group.

2. Materials and Methods

2.1. Study design and participant enrollment

This prospective comparative study was conducted between December 2017 to August 2019. This study protocol was approved by the Institutional Review Board at our institute (Korea University Anam Hospital). Informed consent was obtained from all subjects and/or their legal guardians. This study included PFPS patients with $> 10^\circ$ dynamic knee valgus during a single leg squat task.^[8,28] Physical examination, plain simple radiographs, and magnetic resonance imaging for evaluating knee muscle weakness or tightness, patellofemoral osteoarthritis, abnormal trochlear groove, and patellar height abnormalities were performed by an orthopedic knee surgeon (KMJ). Among the 246 patients diagnosed with anterior knee pain, 209 patients were excluded for the following reasons: chondromalacia, patellar dislocation, patellofemoral osteoarthritis, hamstring and quadriceps muscle inflexibility, and history of knee surgery. Finally, 37 patients PFPS with dynamic knee valgus during a single leg squat task were enrolled in the study, and each patient was treated using the SBE (SBE group, $n = 18$) or the DBE (DBE group, $n = 19$). One patient in the SBE group failed follow-up due to personal reasons. The mean age of enrolled patients was 27.9 ± 5.6 and 26.6 ± 7.6 years in the SBE and DBE group, respectively (Fig. 1).

2.2. Outcome measures

2.2.1. Assessment of dynamic postural stability. Proprioception was evaluated by measuring dynamic postural stability,^[17,29] using the Biodex Stability System (Biodex Medical Systems, Shirley, NY). The foot platform of the Biodex Stability System can be tilted from 0° to 20° and can move 360° . All participants were instructed to stand with both hands kept on the waist with the opposite knee flexed 90° , and to look straight ahead at a point on the wall approximately 1 m away at eye level. The foot location, as determined by the location of the lateral malleolus and the heel cord on the foot plate, was recorded. The dynamic postural stability test was performed twice for 20 seconds each (overall stability index) with blinded screen. The stability level of the foot platform gradually decreased from level 12 (most stable) to level 1 (most unstable) automatically every 1.66 sec. Higher stability index indicated poorer postural stability. In all participants, the test-retest reliability for the dynamic postural stability was evaluated by intraclass correlation coefficients (ICCs) and was good (ICCs = 0.81).

2.2.2. Assessment of isokinetic muscle performance. Acceleration time (AT, sec), defined as muscle reaction time for attaining pre-set angular velocity ($180^\circ/\text{sec}$ in our study) during maximal muscle contraction, was measured to assess neuromuscular control using the Biodex Multi-Joint System 4 (Biodex Medical Systems).^[30-33] A slower AT indicates delayed neuromuscular control.^[32]

Quadriceps strength were measured by maximum torque normalized to body weight (peak torque/body weight, $\text{N}\cdot\text{m}/\text{kg} \times 100$),^[31] and recorded at 60° of knee flexion during maximal knee extension. Each participant was seated in an upright position on an isokinetic chair, the chest fixed to the chair with 2 straps, hips flexed 90° , knees flexed 90° , and holding on to the edge of the chair. The lateral femoral condyle was aligned with the rotational axis of the isokinetic machine. Before testing, the participants performed 5 submaximal flexion/extension repetitions at $180^\circ/\text{sec}$, followed by 15 maximal contractions at $180^\circ/\text{sec}$ after a 1-minute rest period. Gravity correction for torque values was obtained in a relaxed state at 30° knee extension and was calculated using Biodex Advantage software. For all participants, the test-retest reliability of the muscle reaction time and strength of the quadricep muscle was good, with ICCs of 0.77 and 0.86, respectively.

2.2.3. Patient-reported outcomes. The VAS and AKPS were used to measure patient-reported outcomes.^[1,3,4,31] Scores on the VAS ranged from 0 (“no pain”) to 10 points (“worst pain”). The AKPS consists of 13 items, and the total score ranges from 0 to 100 (lower scores indicate higher disability). Based on a previous study for the VAS and AKPS to patient with PFP, a 1.5- to 2-point difference in the VAS and an 8- to 10-point difference in the AKPS were the minimal clinically important differences.^[34]

2.3. Interventions

2.3.1. Static balance exercise. For the SBE,^[35] both hands were kept on the waist, with 45° of knee flexion for 20 seconds (Fig. 2A), which exercise was performed 10 sets. If the participants had difficulty maintaining postural control during the single-leg stand, a stick was used and assistance was gradually reduced.

2.3.2. Dynamic balance exercise. The DBE performed included multi-direction reaching exercises, such as the star-exursion test.^[23,35] The non-symptomatic limb moves in multiple directions, including the anterior, anteromedial, anterolateral, posterior, posteromedial, and posterolateral directions, and the patient holds the same posture as in the static balance exercises (Fig. 2B). This exercise was performed 10 sets.

2.3.3. Knee alignment-oriented methods. Previous studies for alignment of the knee joint^[36,37] have suggested that there should be no medial or lateral movement of the knee during the single-leg exercises, and shoulders and pelvis should be level. Therefore, in this study, for all balance exercises, a strap with a laser pointer attached was wrapped around the thigh, and the laser pointer was used to assist the patient in matching the center line (Fig. 2C).

When postural control became easier during single-leg standing for 20 seconds, the dumbbell weight was added on the opposite side of the standing leg, and performed on the unstable pad. Verbal encouragement was provided during balance exercises.

2.4. Conservative rehabilitation treatment

All patients followed the same conservative treatment protocol for 4 weeks^[38] on both knees to improve muscle strength,

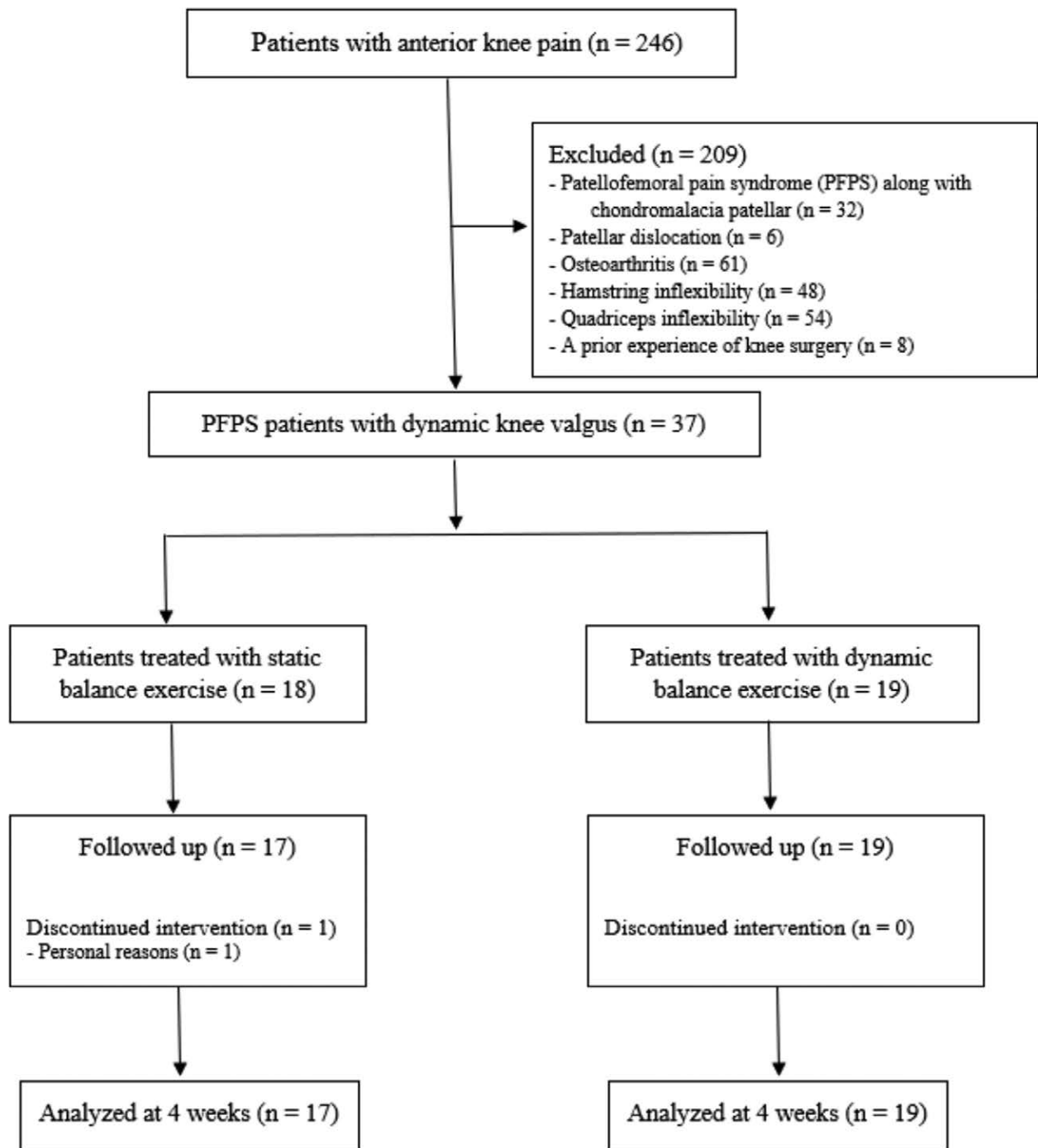


Figure 1. Flow diagram for study participants.

proprioception, and neuromuscular control, and to normalize the biomechanics of the lower extremity, except for the balance exercises. Each participant visited our clinic 2 times a week and performed rehabilitation for 1 hour. They performed both open kinetic chain and closed kinetic chain exercises,^[3,39] including multidirectional front and side plank straight-leg raises with an elastic band, single-leg and double-leg squats below 50° of knee flexion, clamshell side planks, and lateral step up and down using a step box, to improve the quadriceps, hamstrings, hips, and core muscles. In addition, we taught the home routine and recommended it be performed twice a day (in the morning and in the evening).

2.5. Sample size estimation and statistical analysis

Based on a previous study on quadriceps strength^[31] and dynamic postural stability^[40] in patients with PFPS, quadriceps strength difference > 10 % and an OSI difference > 0.5 were assumed to indicate a clinical difference between PFPS patient groups. The sample size was determined using a priori power analysis and an α level of 0.05, at a power of 0.8. A pilot study with 5 patients in each group indicated that a total of 34 patients would be required to detect a significant difference in quadriceps strength (Effect size d: 0.999) and dynamic postural stability (Effect size d: 1.054). In this study, statistical analysis was performed after drop out of 1 participant in the SBE group.

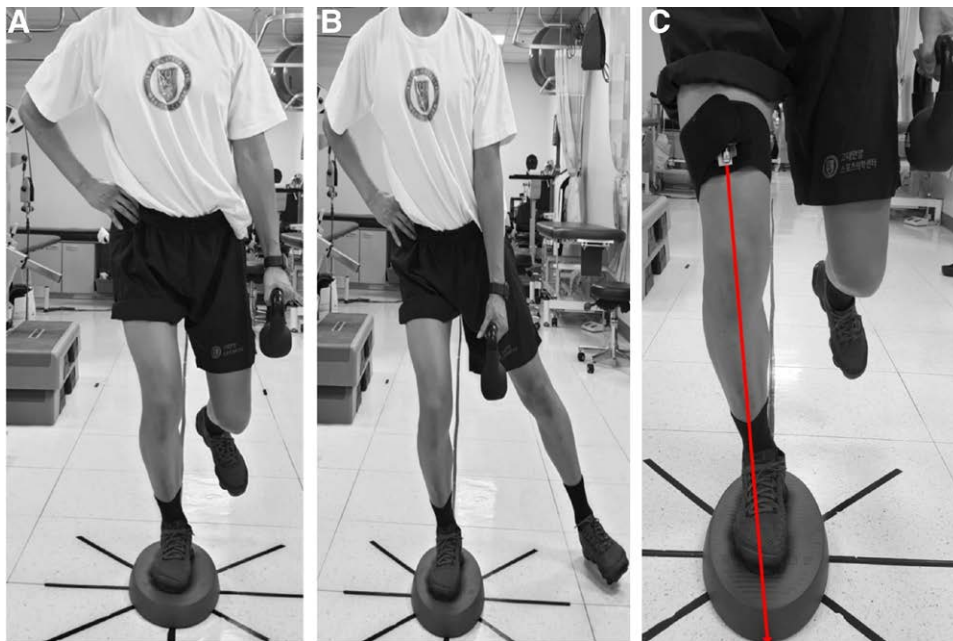


Figure 2. (A) Static balance, (B) dynamic balance, (C) knee alignment-oriented methods.

Therefore, the analysis was performed after data collection from 17 patients in the SBE group and 19 patients in the DBE group. The power for detecting between-group differences in quadriceps strength and dynamic postural stability were 0.771 and 0.823, respectively.

The Student *t* test was used to compare differences in dynamic postural stability, quadriceps AT, quadriceps strength, and patient-reported outcomes between the 2 groups. The paired *t*-test was used to compare all variables before and after balance exercises in each group. Normality of the data distribution was confirmed by Shapiro–Wilk testing. Effect size (Cohen *d*) was calculated to examine the effect of statistical differences, and was classified as weak (≤ 0.49), moderate (0.5–0.79), or large (≥ 0.8).^[41] Data were analyzed using SPSS version 21.0 (IBM Corp., Armonk, NY), and statistical significance was set at $P < .05$.

3. Results

We included 36 PFPS patients with dynamic knee valgus in the analysis, and completed the 4 weeks follow-up assessment. One patient with personal reasons in the SBE group was lost to follow-up. The baseline demographic data are summarized in Table 1, and show no significant differences between the 2 groups (17 in the SBE group vs 19 in the DBE group).

Dynamic postural stability (0.9 ± 0.3 vs 1.2 ± 0.5 , Effect size [Cohen *d*]: 0.72, $P = .021$) and quadriceps AT (40.5 ± 14.3 vs 54.1 ± 16.9 , Effect size [Cohen *d*]: 0.86, $P = .014$) significantly improved in the DBE group compared to the SBE group (Table 2); however, there was similar improvement in quadriceps strength and patient-reported outcomes between the 2 groups (VAS and AKPS, $P > .05$).

In the SBE group, dynamic postural stability ($P < .001$), quadriceps AT ($P = .021$), quadriceps strength ($P < .001$), and patient-reported outcomes (VAS and AKPS, $P < .001$) significantly improved in the symptomatic knee after knee alignment-oriented balance exercises (Fig. 3A).

In the DBE group, dynamic postural stability, quadriceps AT, quadriceps strength, and patient-reported outcomes significantly improved in the symptomatic knee after knee alignment-oriented balances (all $P = .000$ for dynamic postural stability, quadriceps AT, quadriceps strength, VAS, and AKPS, Fig. 3B).

4. Discussion

The most important result of this study was that knee alignment-oriented DBE was more effective at improving dynamic postural stability and quadriceps AT compared to knee alignment-oriented SBE. However, both knee alignment-oriented SBE and DBE significantly improved dynamic postural stability, quadriceps AT, quadriceps strength, and patient-reported outcomes in the symptomatic knees of patients with PFPS.

Although the reasons for more improvement in dynamic postural stability in the DBE group are unclear, one possible reason may be the role of mechanoreceptors and balance test methods. Postural control or postural stability is the motor response (efferent nerves) to sensory input (afferent nerves).^[42] Hence, postural stability can be affected by sensory input from mechanoreceptors,^[29,43] which is composed of Ruffini endings (slow-adapting mechanoreceptors) and Pacinian corpuscles (rapidly-adapting mechanoreceptors).^[29,44] Ruffini endings respond to static posture changes (static postural stability), whereas Pacinian corpuscles respond to dynamic posture changes (dynamic postural stability^[45,46]); that is, static postural stability may be affected by Ruffini endings while dynamic postural stability may be related to Pacinian corpuscles. In the present study, the postural stability test was used to evaluate dynamic balance ability. Therefore, the dynamic

Table 1

Demographic data of participants in the static and dynamic balance groups.

	Static (n = 17)	Dynamic (n = 19)	P value
Sex (male/female)	5/12	8/11	.443
Age (yr)*	27.9 ± 5.6	26.6 ± 7.6	.565
Height (cm)*	166.5 ± 5.4	164.9 ± 7.0	.450
Weight (kg)*	60.5 ± 7.2	59.8 ± 7.4	.763
Body mass index (kg/m ²)*	21.8 ± 2.0	22.0 ± 2.2	.793
Injured side (right/left)	13/4	16/3	.571
Sports and activity, n (low:high)*	6:11	4:15	.304
Insall-Salvati ratio	0.97	1.02	.421

*Values are expressed as mean ± standard deviation.

Table 2
Dynamic postural stability, quadriceps AT, quadriceps strength, and patients-reported outcomes between patients in static and dynamic balance groups.

	Pre-intervention			Post-intervention		
	Static	Dynamic	P value	Static	Dynamic	P value
Dynamic postural stability	1.9 ± 0.4	2.0 ± 0.3	.922	1.2 ± 0.5	0.9 ± 0.3	.021*
MD (95% CI)		-0.1 (-0.3 to 0.2)			0.3 (0 to 0.6)	
Cohen d		-0.28			0.72	
Quadriceps AT	71.2 ± 18.3	73.7 ± 14.6	.651	54.1 ± 16.9	40.5 ± 14.3	.014*
MD (95% CI)		-2.5 (-13.7 to 8.7)			13.6 (2.9 to 24.2)	
Cohen d		-0.15			0.86	
Quadriceps strength	99.2 ± 39.6	86.9 ± 39.9	.359	167.9 ± 47.2	165.0 ± 62.0	.879
MD (95% CI)		12.3 (-14.6 to 39.3)			2.9 (-34.8 to 40.5)	
Cohen d		0.30			0.05	
VAS	4.7 ± 0.8	5.0 ± 1.2	.381	3.0 ± 0.8	2.7 ± 0.8	.331
MD (95% CI)		-0.3 (-1.0 to 0.4)			0.3 (-0.3 to 0.8)	
Cohen d		-0.29			0.37	
AKPS	50.9 ± 10.3	56.8 ± 9.8	.091	71.0 ± 5.2	74.7 ± 6.9	.082
MD (95% CI)		-5.9 (-12.7 to 1.0)			-3.7 (-7.9 to 0.5)	
Cohen d		-0.58			-0.60	

Values are expressed as mean ± standard deviation. The measurement unit of dynamic postural stability was degree. The measurement unit of muscle activation time was milliseconds. The measurement unit of quadriceps strength was Nm kg⁻¹100. The measurement unit of VAS and AKPS was points. All data were recorded and described by one physical therapist. AKPS = anterior knee pain scale, AT = acceleration time, CI = confidence interval, MD = mean difference, VAS = visual analog scale.

*Statistically significant.

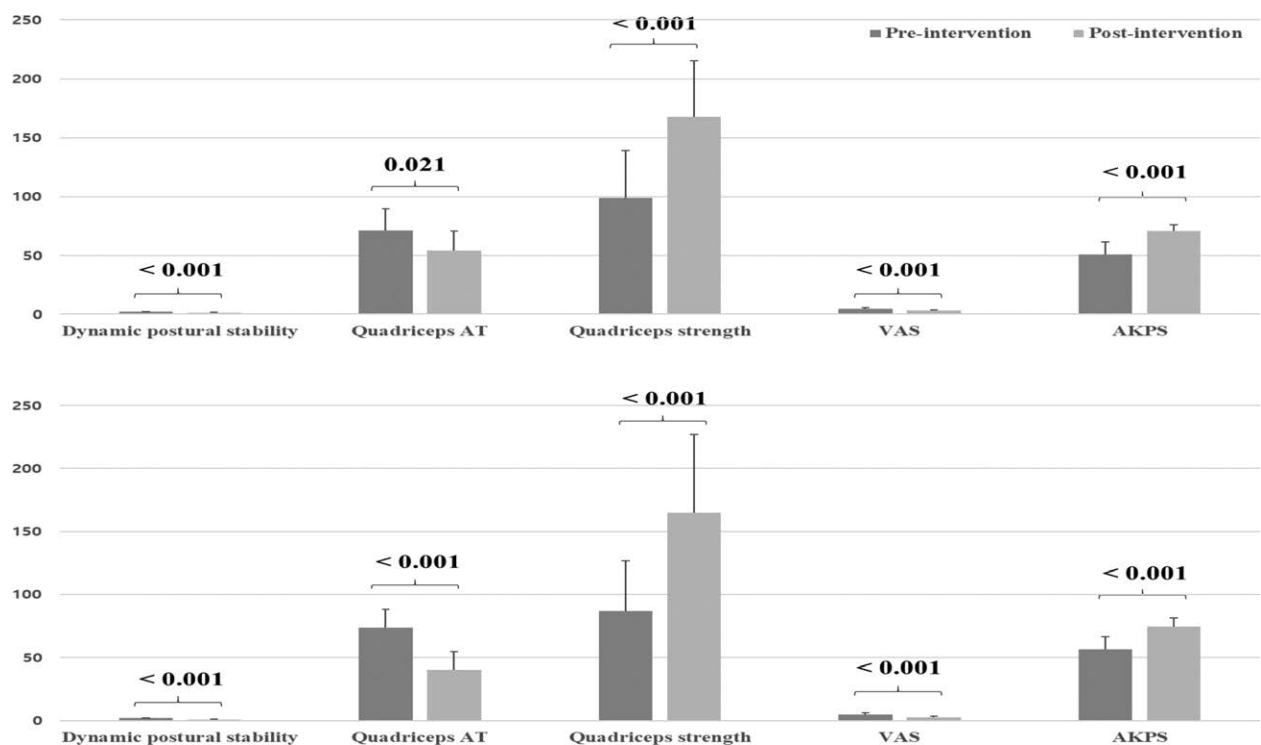


Figure 3. Dynamic postural stability, quadriceps AT, quadriceps strength, and patient-reported outcomes of the symptomatic knees before and after balance exercises in the (A) static and (B) dynamic balance exercises groups. AKPS = Kujala Anterior Knee Pain Scale, AT = acceleration time, VAS = visual analog scale.

postural stability test may have detected activated Pacinian corpuscles more by dynamic balance exercise. Consequently, the dynamic postural stability test may have more reflected DBE than SBE.

Another possible reason may be due to more improved neuromuscular function after the knee alignment-oriented DBE compared with the knee alignment-oriented SBE. Previous studies have reported that muscle coordination or muscle synergy play a significant role in postural stability.^[21,47,48] Therefore, muscle coordination and muscle synergy in the symptomatic knees may have been more enhanced to reduce perturbation for

multiple-directions^[21] during the knee alignment-oriented DBE than during the knee alignment-oriented SBE; the neuromuscular system may have been more enhanced by dynamic postural conditions than static postural conditions.^[19,20] In particular, central nervous system function alters rapidly when changing from static to dynamic posture conditions,^[48,49] which in turn activates the neuromuscular system to stabilize the posture.^[18-21,48] In the present study, quadriceps AT significantly improved in the DBE group compared with the SBE group.

Previous studies have reported reduced quadriceps strength in patients with PFPS.^[50,51] Hence, the conservative treatment

program for quadriceps, hip, and core muscles is important in the reduction of pain and improvement of quadriceps muscle function in patients with PFPS.^[26] According to the results of studies by Steinkamp et al^[52] and Escamilla et al,^[53] squat exercises at 45° of knee flexion may effectively increase quadriceps muscle balance and strength, as a result of low patellofemoral joint reaction and compressive forces.^[54] In the present study, both static and dynamic balance exercises were performed at 45° of knee flexion similar to the squat exercises in the aforementioned study. Moreover, these exercises are useful for strengthening quadriceps and hip muscles to maintain alignment of the hip and knee joints (by adding a dumbbell weight on the opposite side of the standing leg during the balance exercises).^[55] Thus, knee alignment-oriented balance exercises may be beneficial to improve the strength of the quadriceps, hips, and core muscles.^[18,38] In particular, balance exercises in a posture similar to squat exercises lead to eccentric contraction of the quadriceps muscle, which has benefits in improving pain and function in patients with PFP.^[56,57] In the comparison of quadriceps strength in the present study, therefore, there were no significant differences between knee alignment-oriented SBE and knee alignment-oriented DBE.

The results of this study also showed that there were no significant differences in patient-reported outcomes between the two groups. This finding may be due to improved postural stability, neuromuscular control, and quadriceps strength through both knee alignment-oriented SBE and DBE. Previous studies have reported that patient-reported outcomes were associated with postural stability, neuromuscular control, and quadriceps strength; thus, improvement in these areas can directly affect patient-reported outcomes such as pain and functional ability.^[57,58] The results of the present study are in line with this finding and demonstrated significant improvements in dynamic postural stability, quadriceps AT, quadriceps strength, and patient-reported outcomes, with both SBE and DBE. In particular, knee alignment-oriented balance exercises play an important role in improving altered hip and knee biomechanics, such as adduction and internal rotation.^[21,28] Additionally, compared to the minimal clinically important differences results for the VAS and AKPS presented in a previous study,^[34] the VAS and AKPS significantly improved after knee alignment-oriented balance exercises in the present study.

This study has several limitations. The results of this study do not provide evidence that knee alignment-oriented balance exercises are more effective in reducing pain and improving function compared to conventional balance exercises. Therefore, future studies should compare conventional balance exercises with knee alignment-oriented balance exercises to confirm the effect of knee alignment-oriented balance exercises. Furthermore, in this study, each balance exercise was performed along with muscle strengthening exercises for quadriceps, hip, and core muscles, which can be a confusing variable in the results of this study. Therefore, further high-quality researches, including randomized controlled trials, are needed to clarify the effectiveness of these balance exercises. Nevertheless, this is the first study to compare improvements in dynamic postural stability, quadriceps AT, quadriceps strength, and patient-reported outcomes between knee alignment-oriented SBE and DBE in PFPS patients with dynamic knee valgus. Therefore, knee alignment-oriented balance exercises should be considered to enhance dynamic postural stability, quadriceps AT, quadriceps strength, and patient-reported outcomes in patients with PFPS.

5. Conclusions

The results of this study revealed that knee alignment-oriented DBE can be more effective in improving dynamic postural stability and quadriceps muscle reaction time compared with the knee alignment-oriented SBE. However, both types of balance

exercises effectively improve dynamic postural stability, quadriceps muscle reaction time and strength, and patient-reported outcomes. Therefore, clinicians and therapists can recommend knee alignment-oriented SBE and DBE depending on the individual's balance ability in the treatment of PFPS patients with dynamic knee valgus.

Author contributions

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Methodology: Ki Hun Shin.

Supervision: Seung-Beom Han, Ki-Mo Jang.

Validation: Jin Hyuck Lee.

Visualization: Seung-Beom Han.

Writing – original draft: Jin Hyuck Lee.

Writing – review & editing: Ki-Mo Jang.

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