Knee Strengthening With Hip vs. Ankle Exercises in Women With Patellofemoral Pain Syndrome

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Abstract

Purpose: This study compared the effects of knee strengthening combined with either hip or ankle joint exercises on dynamic knee valgus (DKV), visual analogue scale (VAS) scores during activity, tendon stiffness, muscle structure, ankle range of motion, and muscle strength in women with anterior knee pain. **Methods:** Forty-five female recreational athletes aged 20–40 with anterior knee pain were randomly assigned to three groups: hip + knee exercises (HK group, n = 15), ankle + knee exercises (AK group, n = 15), and stretching alone (control group, n = 15). The HK and AK groups received supervised telehealth-based exercise sessions (30 minutes/day, 3 times/week for 8 weeks), while the control group received only an educational pamphlet. Assessments were conducted at baseline, 4 weeks, and 8 weeks.

Key Words: (1) Dynamic alignment (2) Tele-rehabilitation (3) Pain modulation (4) Muscle strength.

Introduction

Anterior knee pain refers to clinical symptoms of pain around the patella that occur during activities such as squatting, running, and climbing stairs due to increased pressure on the patellofemoral joint. Anterior knee pain is a non-contact knee injury, typically characterized by a gradual onset of pain around the knee joint that is not related to trauma. Additionally, the pain tends to worsen with increased activity, leading to limitations in movement and reduced exercise performance (1, 2). Statistics show that this condition accounts for 25-40% of all knee injuries, with a significantly higher prevalence in women than in men (3). This may be related to anatomical differences, particularly the larger knee valgus angle in women. Additionally, characteristics such as muscle strength and muscle coordination in women may also contribute to greater knee joint instability, further increasing the risk of anterior knee pain, impacting quality of life, and raising healthcare costs (4-6).

Treating anterior knee pain is particularly challenging because multiple factors cause it. There is currently no consensus on treatment strategies, but scholars generally agree that the primary causes of anterior knee pain include increased dynamic knee valgus (DKV) angle, weakness in the knee and hip muscles, and poor landing mechanics (7-9). Although the pain associated with anterior knee pain primarily occurs in the anterior knee, the underlying causes are not limited to the knee joint but also involve the hip and ankle joints. Therefore, treatment strategies need to be multifaceted, such as combining hip and quadriceps strengthening, foot and ankle mobility exercises, movement retraining, and patient education, which together target both proximal and distal factors contributing to patellofemoral pain (10-14).

Recent studies have shown that hip muscle control and ankle dorsiflexion range of motion (ROM) influence the DKV angle during weight-bearing activities (15). In the top-down kinetic chain theory, the hip abductor and external rotator muscles eccentrically contract to control hip adduction and internal rotation (16). When these muscles are weak, poor neuromuscular control during weight-bearing activities can lead to increased femoral adduction and internal rotation, increasing the lateral force on the patellofemoral joint (17, 18). This results in excessive load on the patellar tendon and facet joints, which is a key factor in anterior knee pain development (19-21). Numerous studies have demonstrated that weakness in the hip abductor and external rotator muscles can lead to patellar rotation and instability (19, 20). In research by Ferber and colleagues, a three-week hip abduction muscle training program for anterior knee pain patients alleviated knee pain and increased knee stability more quickly than the group that only received knee joint training (22). Furthermore, randomized controlled trials have shown that quadriceps training combined with hip abduction and external rotation muscle training is more effective in reducing knee pain than quadriceps training alone (23, 24). The existing evidence suggests that training both the hip and knee joint muscles is more effective than training the hip muscles alone. Additionally, hip muscle training alone is slightly more effective than knee joint training alone (25). Therefore, studies recommend incorporating hip muscle training into the training programs for anterior knee pain patients (21, 26, 27).

On the other hand, in the bottom-up kinetic chain theory (2), ankle dorsiflexion ROM and the strength of the ankle plantar flexor muscles play crucial roles in absorbing ground reaction forces during landing (28, 29). When ankle dorsiflexion is restricted, patients may compensate for the sagittal plane movement deficiencies by increasing the coronal plane movement (30). In other words, when ankle joint angles are limited, the knee joint may increase the DKV angle as a compensatory strategy, leading to a stiffer landing strategy that increases the knee joint's exposure to greater ground reaction forces during weight-bearing, thereby increasing the risk of anterior knee pain (31, 32). In a proper landing process, the forefoot hits the ground, followed by the eccentric contraction of the plantar flexor muscles to assist in ankle dorsiflexion. Thus, the eccentric contraction capacity of the posterior lower leg muscles also plays a crucial role during weight-bearing (33). In other words, restricted ankle dorsiflexion can affect the entire lower limb kinetic chain, increasing the risk of anterior knee pain.

In daily life or sports environments, single-leg landing is a common movement in many jumping activities. During landing, if the ankle dorsiflexion angle is restricted, the forward glide of the tibia is reduced, requiring compensatory hip adduction and internal rotation (34). This movement pattern in a closed kinetic chain leads to dynamic knee valgus, increases friction along the patellar tracking path, reduces the lower limb's shock absorption capacity, and subjects the patellar tendon to greater ground reaction forces, leading to anterior knee pain (35). Therefore, the single-leg landing test (SLL) is often used to assess lower limb dynamic alignment and evaluate the DKV angle. Compared to single-leg squat tests or step-down tests, the SLL better reflects the actual lower limb alignment during athletic movements (36).

A literature review reveals that only one study has shown that a single session of ankle joint exercise intervention and relaxation can effectively increase ankle dorsiflexion ROM and reduce DKV (37). However, the cases in that study did not involve anterior knee pain, and the intervention was limited to single-session immediate effect. Currently, there is a lack of high-level evidence in the literature to demonstrate that improving the muscle strength around the hip joint and the mobility of the ankle joint can reduce DKV and thereby alleviate the clinical symptoms of anterior knee pain. Notably, there is only one study that specifically explores the relationship between ankle joint interventions, DKV, and anterior knee pain, and this study only examines the effects immediately postintervention (31). More importantly, as mentioned earlier, most assessments focus on changes in pain and biomechanics. To date, no studies have investigated the long-term effects of exercise interventions on the structural changes in the hip, knee, and ankle soft tissues or explored the potential mechanisms of recovery.

Telemedicine is a simple rehabilitation method that overcomes spatial limitations. Particularly during the COVID-19 pandemic, to reduce the risk of face-to-face transmission, many patients were unable to continue their rehabilitation at hospitals (38). As a result, telemedicine became an alternative solution, allowing patients to continue their rehabilitation. Telemedicine not only effectively reduces treatment costs but also improves patient adherence to treatment (39, 40). Telehealth-delivered physical therapy, including telerehabilitation, has been shown in randomized trials to be as effective as face-to-face care for musculoskeletal conditions—yielding comparable improvements in pain, physical function, and quality of life—while systematic reviews report similar outcomes across a broad range of conditions such as low back pain and knee osteoarthritis (41). These findings demonstrate that physical therapy programs can be effectively and successfully administered via telehealth in musculoskeletal populations (42, 43). Although some literature indicates that telemedicine is effective in alleviating pain and improving knee function in anterior knee pain patients, there is still a lack of high-level evidence to support this, and most studies have focused solely on clinical symptoms (44). Therefore, this study adopted 8 weeks of telemedicine as an intervention strategy to further understand the benefits of combining hip or ankle joint exercises on exercise performance, clinical symptoms, and tissue structure in female patients with anterior knee pain. We hypothesized that 8 weeks of telehealth-based supervised exercise, both the hip and ankle, coupled with knee strengthening, would effectively improve DKV and pain in women with anterior knee pain, and both groups would provide comparable benefits.

Methods

All participants provided written informed consent for this study, which was approved by the Institutional Review Board of Kaohsiung Medical University Chung-Ho Memorial Hospital (Approval Number: KMUIRB-E(I)-20220334). Before the formal trial begins, the examiners received comprehensive testing training. Each participant will also be familiarized with all experimental procedures and testing items.

Participants

A total of 45 female recreational athletes with anterior knee pain were recruited. We only included females in the current study due to their approximately twice the risk of anterior knee pain compared to males (3). Cases were required to be evaluated by orthopedic or sports medicine physicians to confirm the diagnosis of anterior knee pain. To exclude the possibility of joint degeneration, the participants' age was restricted to 20-40 years. Recreational athletes were defined as individuals who participate in aerobic exercise or physical activities at least three times per week for a minimum of 30 minutes per session. Inclusion Criteria: (1) Female recreational athletes aged 20-40 years who engage in regular exercise; (2) Experiencing pain in the anterior or surrounding patella during at least two or more of the following activities: walking, running, jumping, kneeling, squatting, climbing stairs, or prolonged sitting; (3) A pain index of 3 or higher on the Numeric Pain Rating Scale (NPRS) and symptoms persisting for at least 3 months; (4) Knee pain unrelated to trauma. Exclusion Criteria: (1) Inability to operate a smartphone or computer; (2) History of fractures or surgeries involving the hip, knee, ankle, or foot; (3) History of meniscus, knee ligament injuries, or ankle sprains within the last six months; (4) Knee ligament laxity, inflammation, swelling, patellar dislocation, or subluxation; (5) Cognitive impairment or inability to follow simple instructions; (6) History of cardiovascular or neurological disorders; (7) Advised by a physician to avoid exercise. Use of over-the-counter pain medication was not an exclusion criterion. Participants were instructed to maintain their usual medication habits and to refrain from initiating new oral analgesics for knee pain during the intervention period. At baseline, no participants reported regular use of oral analgesics for anterior knee pain, and no changes in medication use were reported during the study.

Experimental Procedure and Random Grouping

A single-blinded randomized controlled trial was conducted, in which outcome assessors were blinded to group allocation to reduce the risk of bias. Upon arrival at the research laboratory, participants first performed a simple warm-up (5 minutes of cycling) before immediately undergoing pre-tests. The measurements were conducted in the following order: pain index assessment, patellar tendon stiffness measurement, ultrasound examination, ankle joint ROM measurement, DKV angle measurement, and maximum muscle strength measurement. After completing the pre-test (T0), participants randomly drew a numbered card from an opaque box to determine their group assignment for the subsequent 8-week exercise intervention: Group A (ankle + knee joint exercise group, AK), Group B (hip + knee joint exercise group, HK), or Group C (stretching group). After grouping, participants were immediately instructed on and performed the assigned exercise intervention once. Following three training sessions per week, post-tests (same as pre-tests) were conducted at the 4th week (T1) and the 8th week (T2) (Figure 1). Throughout the exercise training period, participants were guided and monitored by a professionally trained physical therapist.

Interventions

Participants in the hip + knee joint exercise group (HK group) and the ankle + knee joint exercise group (AK group) received one-on-one exercise instruction from a physical therapist with a background in sports medicine. The exercise training goals for the HK group included strengthening the knee extensors (Figure 2(a) Primarily targets the quadriceps (knee extensors), improving knee extension strength and stability 2(b) Also strengthens the quadriceps, with greater isolation of the knee extensors compared to (a), focusing on controlled terminal knee extension 2(c) Works the quadriceps, gluteal muscles, and to some extent the hamstrings, emphasizing closed-chain strengthening and functional loading of the lower limb, while also training postural control), hip external rotators (Figure 3(a) Strengthens the hip abductors (particularly gluteus medius) while promoting pelvic stability during lateral movement 3(b) Activates the gluteus maximus and posterior chain muscles, with added hip abductor engagement from the resistance band 3(c) Specifically targets the hip external rotators (gluteus medius, gluteus minimus, piriformis) to improve control of hip rotation and reduce dynamic knee valgus 3(d) A progression of (a) that increases challenge to the hip abductors and lateral stabilizers, requiring greater control at the knee and ankle 3(e) Glute bridge with one leg raised using a resistance band – An advanced form of (b), training unilateral gluteal and core strength, while also engaging hip abductors and extensors for pelvic stabilization 3(f) Isolates the gluteus medius and hip abductors, critical for controlling frontal-plane motion and stabilizing the pelvis during single-leg tasks), and hip abductors (Figure 3). For the AK group, the training goals included strengthening the knee extensors (Figure 2), ankle dorsiflexors (Figure 4(a) Strengthens the ankle plantarflexors (gastrocnemius, soleus), improving calf strength and lower-limb push-off power 4(b) A progression of (a) that further develops plantarflexor strength and enhances ankle stability and balance under unilateral loading 4(c) Increases ankle dorsiflexion ROM by mobilizing the talocrural joint, improving tibial forward glide during weight-bearing 4(d) Strengthens the dorsiflexor muscles (tibialis anterior, extensor digitorum longus), enhancing control of foot clearance during gait and landing 4(e) Stretches the gastrocnemius–soleus complex, improving ankle flexibility and reducing compensatory movement patterns), and plantar flexors (Figure 4), as well as performing ankle joint self-mobilization and stretching exercises (Figure 4). The therapist ensured that the participants were familiar with and correctly performing the exercises before they left. At the end of the session, participants were provided with a home exercise demonstration handout to be performed three times per week for eight weeks. The handout included precautions to take during exercise, guidelines for managing exercise injuries, and a contact number for consultation.

Home exercise training was remotely supervised. During the home exercise period, participants engaged in moderate-intensity exercise (rate of perceived exertion, RPE, 12-14) three times per week. Each exercise was performed in two sets, with each set consisting of 10-15 repetitions according to the training plan, and the total exercise time was approximately 30-45 minutes. The therapist used communication software to supervise participants one-on-one remotely, guided them through the exercises, monitored their RPE, and provided individualized, gradual adjustments as needed. The therapist also corrected participants' posture and movements if necessary and adjusted the length or resistance of the resistance bands to increase or decrease exercise intensity based on the participants' abilities.

Participants in the stretching group received a knee exercise handout and were instructed on quadriceps and hamstring stretching exercises at baseline. Unlike the HK and AK groups, no remote supervision, monitoring, or follow-up was conducted for the stretching group. This group functioned as the unsupervised control condition.

Outcome measures

Primary Outcome (DKV)

The Single Leg Landing Task (SLL) was used to measure the DKV angle during single-leg landing. The participant stood on a 30 cm box and first bent the non-testing leg's knee to approximately 90 degrees. After stabilizing, the participant jumped forward with the testing leg to a target 10 cm away from the box, maintaining balance for five seconds upon landing. During the test, the non-testing leg was not allowed to touch the ground, the participant was instructed to keep their eyes looking forward, and both arms were crossed over the chest to minimize the influence of arm movement. The entire sequence was repeated twice, and video recordings were made using a smartphone (45). Image Analysis: Before recording, markers were placed on the midpoint of the knee joint (midpoint of the line connecting the medial and lateral femoral condyles), the midpoint of the ankle joint (midpoint of the line connecting the medial and lateral malleoli), both anterior superior iliac spines (ASIS), and the midpoint of the line connecting the ASIS and the knee joint. A smartphone camera was positioned 2 meters in front of the participant to record the video. The video was then analyzed using Kinovea software version 0.8.27 (https://www.kinovea.org/download.html) to measure the two-dimensional frontal plane projection angle (FPPA). The knee valgus angle was calculated by subtracting the obtained angle from 180 (the larger the value, the greater the knee valgus angle). The sequence was repeated twice, and the average value was taken.

Secondary outcomes

Numeric Pain Rating Scale (NPRS): The NPRS is an 11-point scale where 0 indicates no pain and 10 indicates the worst pain imaginable. Participants were asked to rate their perceived pain both at rest and during weight-bearing in a lunge position (46, 47).

Patellar Tendon Stiffness Measurement: The stiffness of the patellar tendon was assessed using a handheld device (MyotonPRO; Tallinn, Estonia). Participants were seated at the edge of a bed with their knees bent at 90°. The tension was measured 3 cm below the apex of the patella, with the assessment repeated three times. The average value was taken as the patellar tendon stiffness (48).

Muscle structure: A portable ultrasound device (Linear wireless probe LU700L VET) was used to assess the structure of the gastrocnemius and gluteus medius muscles in a resting state. Ultrasound images were used to record muscle thickness (MT) and pennation angle (PA). The pennation angle was defined as the angle between the deep fascia and muscle fibers. Muscle thickness was defined as the length of a perpendicular line drawn from the origin of the muscle fibers at the deep fascia to the superficial fascia, based on the pennation angle (49). Gastrocnemius: Participants lay prone on a bed with a towel placed under the knee to flex it to 20°-30°, and the ankle was fixed at 90° using a goniometer. The ultrasound probe was placed parallel to the gastrocnemius muscle fibers, and the scanning depth was adjusted to 6.3 mm to display both the deep and superficial fascia. The pennation angle was defined as the angle between the deep fascia and muscle fibers. Muscle thickness was measured as the length of a perpendicular line drawn from the origin of the muscle fibers at the deep fascia to the superficial fascia (49). Gluteus Medius: Participants lay on their side, with the test leg on top, and the hip and knee joints in a neutral position. The ultrasound probe was placed between the iliac crest and the greater trochanter, parallel to the gluteus medius muscle fibers. The greater trochanter was positioned in the lower right third of the image as a landmark to increase measurement consistency, with the gluteus medius centered in the image for recording (50).

Ankle Joint ROM: Since patients with anterior knee pain often experience knee pain during weight-bearing activities, this study used a weight-bearing lunge test to measure the active dorsiflexion angle of the ankle during weight-bearing. A measuring tape was placed on the floor, with the participant's heel and second toe aligned with the tape. The participant started with their toes 10 cm from the wall, touching the wall with the knee while keeping the heel on the ground. The heel must maintain contact with the floor. If the participant could easily touch the wall or could not reach it, the distance was adjusted by 1 cm increments, gradually adjusting the distance forward or backward according to the participant's ability until they could no longer keep the heel fully in contact with the ground. At the maximum angle, a goniometer was used for measurement, with the fixed arm placed flat on the ground and the movable arm aligned with the line connecting the lateral malleolus and the head of the fibula. The test was repeated twice, and the average value was recorded (51).

Maximum Voluntary Isometric Strength: A handheld dynamometer (MicroFET3; Hoggan Scientific LLC, USA) was used to measure the maximum isometric strength of the hip abductors, knee extensors, ankle dorsiflexors, and ankle plantar flexors. Each test was repeated twice, and the average value was recorded (52).

Statistics

The sample size for this experiment was estimated using G*Power and calculated using the priori sample size for Repeated Measures ANOVA. The effect size (ES) was set at f = 0.45, with an alpha value of 0.05 and a power of 80%. Based on the above calculations, the required sample size was 36 participants. Considering a potential 10% dropout rate, 40 eligible participants were to be recruited. However, to increase the statistical power, the final target was to recruit 45 participants.

Data processing and analysis were conducted using SPSS 20.0 for Windows statistical software. The significance level for all data was set at $p < 0.05$, and all numerical data were presented as mean ± standard deviation. The Shapiro–Wilk test was used to determine the normality of the data distribution. If the data were normally distributed, a two-way ANOVA with repeated measures was used to analyze the 3 group factors (hip + knee group, hip + ankle group, stretching group) x 3 time factors (pre-test, week 4, post-test) to first examine the significance of the interaction effect. If the interaction effect was significant, indicating that the group and testing time factors influenced each other, a simple main effect test and Bonferroni post hoc comparisons were performed. A One-way ANOVA analysis was used to compare intra-group differences before the intervention, followed by Bonferroni post hoc comparisons. Training adherence was calculated using the formula: (actual training sessions/24) * 100%. Test-retest reliability was verified using the Intraclass Correlation Coefficient (ICC) to ensure the consistency of all measurements.