



***Rehabilitation
& Performance***
INSTITUTE

The Knee



The Knee

ASSESS

Initial observation

- Observe gait pattern, compensation, and braces

Inspection

- Observe standing posture
- Posterior
 - Medial arch, calcaneal deviations, swelling, popliteal folds, PSIS, iliac crests, greater trochanter, fibular head
- Anterior
 - ASIS, forefoot position, ankle mortise direction, anterior tibial tubercle, patellar direction and level, knee varus/valgus, swelling, Q angle
- Lateral
 - Recurvatum of knees, position of pelvis, lumbar and thoracic curves
- Local
 - Color changes, localized or general swelling, muscle atrophy, patellar alignment

Function

- Gait: walking forward/backward
- Single leg stance for proprioception and balance
- Single leg stance: flexion, extension, internal/external rotation in wearing
- Check equal wt bearing-symmetry of movement during squatting

Palpation

- Knee and hip functions

Passive and Active ROM

- Flexion
- Extension
- Internal rotation
- External rotation

Resisted Testing

- Test in 3 positions beginning in neutral, then fully shortened and fully extended.

Neurology

- Motor:
 - Femoral N: L2-4
 - Sciatic N: L5, S1-S2
 - Obturator N: L2-4 (gracilis)
 - Tibial N: S1-2
- Myotomes:
 - L2: Hip flexion
 - L3: Knee extension
 - L4: ankle DF
 - L5: Great toe extension
 - S1: Ankle PF
 - S2: knee flexion
- Reflexes:
 - L4: patellar tendon reflex
 - L5: Medial hamstrings reflex
 - S1-2: lateral hamstring reflex
 - S1: Achilles reflex
- Sensation (Sharp and light touch)
 - L2-anterior femoral cutaneous N-medial front half of the thigh and knee
 - L3-anterior femoral cutaneous N-medial front half of the thigh and knee
 - L4-lateral femoral cutaneous N-lateral front half of the thigh and knee
 - L5-common peroneal N-lateral anterior calf
 - S1-Posterior Femoral Cutaneous-posterior aspect of the thigh and knee
 - S2-Genital area

Special Tests:

- Muscle Flexibility Tests
 - OBER: TFL, ITB
 - Modified SLR: hamstring
 - Elys Test: Quadriceps
 - Gastroc/Achilles length test
- Patellofemoral Tests-tests for retropatellar pain or chondromalacia
 - Patellar apprehension
 - Patellar Compression
 - Patellar Tilt
 - Moving patellar apprehension
- Meniscus
 - McMurrays Test: Sn= .37, Sp= .77
 - Apleys Compression: Sn .61, Sp .70
 - Eges Test: Sn=.88/.67 Sp= .44/.80
 - Thessalys Test: Medial: Sn=.66, Sp=.96, Lateral: Sn=.81, Sp= .91
 - Bounce Home Test
 - Joint line tenderness: Sn .76, Sp .77

- ACL
 - Lachmanns: Sn=.99, Sp=1.0
 - Anterior Drawer: Sn=.78, Sp=1.0
 - Lateral Pivot shift: Sn=.87, Sp=1.0
- PCL
 - Posterior Drawer: Sn=.90, Sp=.99
 - Posterior sag sign: Sn=.79, Sp=1.0
 - Posterior lateral drawer test
 - Dial Test
- MCL
 - Valgus Stress Test: Sn=.86, Sp=.93
- LCL
 - Varus Stress Test: Sn=.25, Sp=.99

Specific Joint Mobility Testing

- Patellofemoral joint
- Proximal Tibiofibular joint
- Tibiofemoral Joint
 - Remember to assess lumbar spine, feet and ankles.

SFMA-assess and perform breakouts as needed. The knee will be involved in many of the breakouts and regionally above and below the joint.

Squat Breakout
<ul style="list-style-type: none"> • Feet together, arms out- Squat down and break Parallel- Hands Down- Stand up • Inversion/Eversion of Feet • Supine Knees to Chest Holding Shins Test • Supine Knees to Chest Holding Thighs Test • DF with knees flexed 20-30 degrees

RESET THE SYSTEM

Knee Mobilizations

Tibiofemoral (Concave on Convex)

- Distraction- in sitting
 - Oscillations v. Static hold



Use ankle mobilization belt around patient's ankle to give distraction force with foot.

Pull down and perform posterior glide at the same time.

Can also work into more flexion in this position.

- Posterior glide for flexion (combine IR)
- Anterior glide for extension (combine ER)
 - Posterior or anterior glides with belt: If want greater than 80% plasticity at a certain force, can use pulleys to mobilize a joint segment for you.
 - Anterior glide with mobilization belt in prone

****Can perform tibial internal and external rotation with the foot fixed as well.**



Bend knees, lean back into belt, and work into extension.

Proximal Tibiofibular

Why is this important? Posterior fixation of the head of the fibula limits knee flexion.

- Posterior-Medial
- Anterior-Lateral
 - Compare to opposite side for assessment in sitting and possibly hooklying
 - Seated, hooklying, or side lying



Anterior-Lateral Mobilization in Sidelying

Mold the hands gently around the head of the fibula in order to prevent irritation of the peroneal nerve.



Posterior-Medial Mobilization in Sidelying



Posterior-Medial Mobilization in Hooklying

Patellofemoral

- If limited knee flexion, pinch inferior fat pad, glide distally
- Work into greater flexion as mobilize

Considerations:

- Mechanoreceptors=type II
- Blocking with wedges and lower extremities
- Open-packed position: Slight flexion (25 degrees)

Manual Techniques to Reset Squat Breakout:

Purpose	Technique	Set Up	Direction of Force
Dorsiflexion TED/Ankle JMD	Graded mobilization into dorsiflexion	Patient position Prone, knee flexed 90 degrees Therapist position, One hand cups proximal calcaneus -- Other hand grasps midfoot with forearm placed along plantar foot	Forearm pressing downward toward knee
Dorsiflexion TED/Ankle JMD	Rearfoot Distraction Manipulation	Grasp the dorsum of the patient's foot with interlaced fingers -- Provide firm pressure with both thumbs in the middle of the planar surface of the forefoot -- Engage the restrictive barrier by dorsiflexing the ankle & applying long axis distraction -- Pronate & dorsiflex the foot to finetune the barrier	Apply a high velocity, low amplitude thrust in a caudal direction
Dorsiflexion TED/Ankle JMD	Talocrural Joint AP Mobilization	MANIPULATION -- Use one hand to firmly stabilize the lower leg at the malleoli -- Grasp the anterior, medial, and lateral talus with your other hand -- Apply an anterior to posterior oscillatory mobilization force to the talus	Tip: -- Use your thigh to help stabilize the foot and to progressively increase the amount of ankle dorsiflexion used with this technique -- You may need to adjust the amount of supination / pronation to optimize the technique
Knee Flexion JMD/TED	Supine Knee Flexion	Standing on the side to be treated, facing toward the patient's head, grasp the patient's proximal leg with both arms, placing the palm of	Use your body to flex the knee into desired range within the joint for treatment effect (within or out of resistance). Use your body and arms to impart

		your hands just inferior to the tibiofemoral joint line. Cradle the lower leg between your arm and body.	graded large amplitude mobilizations to the knee. Keep knee and hip in straight plane motion.
Hip Flexion JMD/TED	Hip Flexor Manual Stretch	<p>Patient supine at the edge of the table with the patient's contralateral hip flexed to approximately 100-110 degrees and the ipsilateral knee hanging off the table. Position the patients contralateral hip in flexion and place their foot against your side at roughly the level of the iliac crest. Place your cephalad hand on the patient's anterior-superior iliac spine and provide gentle downward stabilizing pressure. Place your caudal hand on the anterior aspect of the distal femur and provide gentle downward pressure until resistance is encountered</p>	<p>To target the iliopsoas muscle, simply provide a downward force to the femur and hold the stretch for 30 seconds or more.</p> <p>To target the rectus femoris, hook your caudal ankle around the patient's lower leg and introduce knee flexion.</p> <p>To target TFL muscle, hook your caudal ankle around the patient's lower leg and introduce hip adduction and external rotation until the patient perceives the stretch in the region of their TFL muscle</p>

REINFORCE THE CORRECTION

Patient Education:

- Education regarding footwear
- Activity modification
- Edema control
- Sleeping positions
- Driving
- ADLs/ ANLs
- Brace wearing

Basic Reinforcement Interventions:

- “The Stick” – Reinforces any soft tissue work and helps remove additional TEDs
 - Along quadriceps, hamstrings, gastrocnemius/ soleus, ITB
- Foam Roller- Reinforces any soft tissue work and helps remove additional TEDs
 - Along quadriceps, hamstrings, gastrocnemius/ soleus, ITB, hip flexors, piriformis
- Stretches- assisting with various TEDs
 - Quadriceps, hamstrings, gastrocnemius/ soleus, ITB, hip flexors, piriformis, adductors, hip internal and external rotators, quadratus lumborum, pretzel stretches, quadruped rock backs, butterfly stretch, DKTC

OA Bracing

PROGRESSION: UNLOADER 1, DONJOY NANO, SPIRIT UNLOADER

- **Ossur** – 30-day trial on brace
 - **Unloader one and the Unloader one XI**
 - Unloader- clasps are difficult (go to Nano Donjoy if have difficulty)
 - Start with lined up higher than mid-patella; Snap in blue, then snap in yellow
 - “X” of straps in popliteal space
 - Control pressure by pulling strap in back- keep in 5-6 range (do not allow patient to adjust the pressure on their own).
 - Fit in 30 degrees flexion
- **Spirit Unloader**- go to this last if they cannot get in other braces; or cannot have surgery.
 - Strapping- calf first; strap across - pad over suprapatellar area over VMO; to traction ST away; 3 pads (if need more pads can add them in if need) in and then tighten down with special key; take out pads. Only need 8-9 deg correction at first.
 - Braces take away 15-20% of pressure when walking (looking for mm of difference).
 - Wearing Schedule: Start with 1.5 hours of wear and when knee goes back to normal pain, increase by .5 hr every day to couple days. Wear full time inside of 2 weeks.
 - Not very helpful with grade IV collapse

DonJoy

- Nano, can use OA everyday or OA Defiance, OA Full Force
 - NANO: comes with 6 degrees correction built in
 - Tighten half screw and then let them walk
 - Can back down to 1 degree if it is too much
 - Extension or flexion stop (put in and screw down)

Ligament Bracing

Donjoy

- **ACL and PCL, use a full force**
 - 15 degree slow down from extension; adjust to 15-30 lb. -(3rd hole = most stable; 1st hole= less stable) keep in if you are worried about pt. returning to sport ; take out if you are not worried about them; decision up to me.
 - <http://www.youtube.com/watch?v=7O6B8ZbdOyo>
- **MCL, use a Playmaker, full force**
 - All with popliteal cut out; can get closed or open (closed for bigger leg); Bottom 3rd even with midline of patella- adjust bottom strap around calf then top strap

Functional Taping:

For Example:

- *Medial Tibial Rotation Taping:* use taping techniques to assist with lateral rotation of the tibia
- *Patellofemoral Tracking:* McConnell taping for patellofemoral pain (**YouTube**)
 - Can use to help glide the patella medially

Reinforcement Techniques for Squat Breakout:

Purpose	Technique	Set Up or Directions
Progress more ankle dorsiflexion	Standing MWM to Increase Dorsiflexion	Grasps and support the arch of the foot. Apply a stabilizing force over the anterior talus. Place a belt or band over the posterior distal leg of the patient and around the clinician's buttock region. Guide the patient into dorsiflexion while simultaneously producing a posterior to anterior force to the distal leg by leaning backwards/ pulling on the belt or band Adjust the forces, direction of motion, and stabilization until the patient experiences a pain-free motion of ankle dorsiflexion.
Knee Flexion JMD	Mobilizing knee for flexion	Place towel under femur. Bring up to restriction barrier and mobilize there Modified 'posterior drawer': can put knee at 90° while pt. is in supine (make sure to change direction of force applied)
Knee Flexion JMD	Mobilizing knee for flexion	Posterior glide tibia on femur, seated. Place both hands on the proximal lateral tibia and fibula and mobilize in posterior direction.
Hip Flexion	Hip Distraction	Hip in resting position (30 degrees flexion, 30 degrees abduction, 20 degrees external rotation). Distract by leaning away from pt. and gliding femoral head in lateral, inferior and posterior direction.
Hip JMD/TED	Hip Manip: Long axis distraction of the hip joint	Do some oscillations to get pt to relax and find where hip feels most open. Usually best in OPP: 30° Flex 30° Abd 20° for oscillation and manipulation. Take up slack a few times, each time a little more than one before. Manipulation comes from body, don't lean back (*only needs a slight thrust, sometimes goes during warmup)
Femoral Nerve involvement	Anterior Hip Nerve Flossing	Patient is propped on up elbows in a prone position. Neck extension with one knee flexed to begin. Take neck into flexion allowing tension along the femoral nerve track even though lumbar extension may put slack in the track.

RELOAD THE SOFTWARE

Once mobility is established at the dysfunctional joint, treat as a SMCD and reload the system so that the patient can utilize their new mobility in a functional manner.

<i>Corrective Matrix for Squat Breakout</i>				
<i>Posture</i>	Standing	Deep Squat with Pattern Assistance (Valgus Stress)	Overhead Squat Progression	Deep Squat Lateral Challenge with Pattern Assistance Resisted Overhead Deep Squat (on shoulders)
	Stacked Spine (Kneeling)	Tall Kneeling Chop/Lift Pattern with Pattern Assistance	Tall Kneeling Chop/Lift Pattern	Tall Kneeling Chop and Lift with Resistance
	Suspended Spine (Quadruped)	Quadruped Posterior Rocking with Pattern Assistance	Quadruped Posterior Rocking	Resisted Quadruped Rocking
	Supported Spine (Supine/Prone)	Dorsiflexion Ball Rolls with Pattern Assistance	Dorsiflexion Ball Rolls	Resisted Dorsiflexion Ball Rolls
		Facilitate (Expresses Mobility)	Demonstrates (Expresses Competency)	Challenges (Expresses Motor Control)

RUNNING CORRECTIVE EXERCISES

PROBLEM	CORRECTION
Strong heel strike	Forward lean of the torso by 10 degrees
Overstriding	Incline TM to 5% to teach runner to take shorter strike and land more foot-flat than heel Metronome (increase steps per minute- around 180 bpm) Check hip extension- is it limited therefore causing them to overuse hip flexors?
Crossing over the midline	Place tape on middle of TM and place mirror in front of runner to keep them in the midline
Decreased hip flexor drive toward next stride- lacks strong push-off and circumducts tibia	High knee drills – use arms to assist with hip flexor drive “up” towards next stride Hopping over cones- double leg then single leg Scissor lunge lumps
Contralateral hip drop- Ipsilateral gluteus medius weakness	Watching ASIS in the mirror- putting tape on them so they do not drop in the mirror Single leg squats in front of mirror Double leg side-to-side jump “skier’s pose” Focus on level pelvis Single leg plyometric training Single leg ladder drills/ hop scotch
Excessive trunk flexion	Kinesiotape mid-thoracic spine along erector spinae to gluteus max bilaterally Planks on/ off stability ball Lunges with upright trunk progressing to scissor lunges and other plyo drills Strengthen core: TA/multifidus/internal obliques/ QL/ superficial pelvic stabilizers
Knee valgus with contact through midstance	Hip abductor/ extensor/ external rotator strength (eccentrics)
Overpronation	Improve strength to post-tib, gastroc-soleus, hip abductors, hip external rotators, hip extensors (eccentrics) Improve flexibility to gastroc/ soleus Orthotics- only after you make sure patient has normal hip strength, calf strength, flexibility, ankle mobility Toe Yoga
Assymmetric foot slap	Avoid overstriding Tell patient to land with “soft feet” Plyometric training on feet
Early heel rise	Improve DF ROM Improve soleus flexibility

Functional Hop Testing

Tests:

- Single hop for distance
- 6-m Timed Hop
- Triple hop for distance
- Crossover hop for distance

Procedures:

- One practice trial for each limb.
- Begin with non-operative limb.
- Rest in between (30 seconds) to avoid fatigue.
- For the hops for distance (single, triple, and crossover) to be deemed successful, the landing must have been maintained for 2 seconds.
- Unsuccessful hop:
 - touching down of the contralateral lower extremity
 - touching down of either upper extremity
 - loss of balance
 - additional hop on landing
 - If the hop was unsuccessful, the subject was reminded of the requirement to maintain the landing, and the hop was repeated. No further instructions were provided to the subjects. Typically, 1 or 2 extra trials are required.
- Distance hopped:
 - measure at the level of the great toe
 - measure and record to the nearest centimeter from a standard tape measure
- Timed 6-m hop:
 - Large one-legged hops in series over the total distance.
 - A standard stopwatch used to record time
 - Start when a subject's heel lifted from the starting position and stop the moment that the tested foot passes the finish line
 - Measurements recorded to nearest 10th of a second.

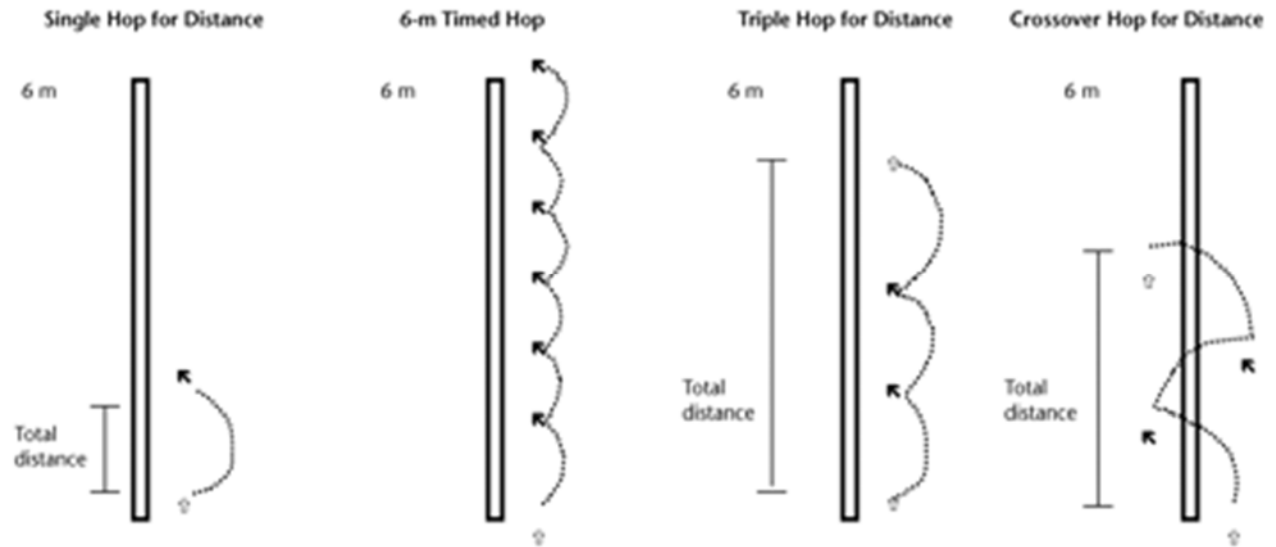


Figure: Diagrammatic representation of the series of 4 hop tests: single hop for distance, 6-m timed hop, triple hop for distance, and crossover hop for distance. Adapted and reprinted by permission of Sage Publications Inc from: Noyes FR, Barber SD, Mangine RE. Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. Am J Sports Med. 1991;19: 513–518. Copyright 1991 by Sage Publications Inc.

What to do with the data: Enter Data in Move2Perform Software

Table 4.

Mean \pm Standard Deviation (Minimum–Maximum) for Male Subjects for Hop Test Absolute Scores on the Operative and Nonoperative Limbs, the Limb Symmetry Index (Operative Limb Expressed as a Percentage of Nonoperative Limb), and the Lower Extremity Functional Scale Scores on 4 Separate Test Occasions

Test	Day 1 (16 wk Postoperatively)	Day 2 (+24–48 hr)	Day 3 (+24–48 hr)	Day 4 (22 wk Postoperatively)
n	23	23	17	21
Single hop				
Operative limb (cm)	117.0 \pm 36.8 (44.0–179.5)	136.4 \pm 32.4 (70.0–187.5)	136.7 \pm 35.4 (70.5–192.5)	148.5 \pm 28.5 (96.5–187.5)
Nonoperative limb (cm)	139.8 \pm 35.9 (71.5–204.0)	165.1 \pm 26.9 (115.5–213.5)	171.1 \pm 26.9 (123.0–215.0)	167.3 \pm 25.3 (122.0–212.0)
Limb symmetry index (%)	84.1 \pm 16.8 (33.8–110.1)	82.1 \pm 11.0 (50.5–99.7)	79.1 \pm 11.8 (51.6–92.9)	88.5 \pm 8.8 (71.5–102.7)
6-m timed hop				
Operative limb (s)	3.1 \pm 1.9 (1.7–9.1)	2.7 \pm 1.1 (1.8–6.4)	2.7 \pm 1.3 (1.7–6.0)	2.4 \pm 0.6 (1.6–4.0)
Nonoperative limb (s)	2.3 \pm 0.6 (1.6–4.5)	2.2 \pm 0.4 (1.5–3.5)	2.1 \pm 0.5 (1.5–3.1)	2.1 \pm 0.4 (1.5–2.9)
Limb symmetry index (%)	83.1 \pm 16.7 (33.8–99.6)	82.4 \pm 12.5 (47.5–102.8)	81.8 \pm 14.4 (50.2–100.3)	89.5 \pm 9.2 (70.4–100.7)
Triple hop				
Operative limb (cm)	375.4 \pm 93.1 (183.0–532.5)	391.3 \pm 86.0 (255.0–570.0)	401.3 \pm 99.0 (231.5–553.5)	419.8 \pm 87.7 (279.0–618.0)
Nonoperative limb (cm)	438.8 \pm 86.1 (265.5–576.5)	466.5 \pm 83.2 (317.5–606.5)	496.0 \pm 85.4 (302.5–633.5)	483.4 \pm 98.6 (310.5–666.5)
Limb symmetry index (%)	85.6 \pm 12.9 (45.1–99.6)	84.0 \pm 11.0 (55.5–99.7)	80.6 \pm 12.7 (57.2–96.2)	87.4 \pm 10.2 (68.0–101.3)
Crossover hop				
Operative limb (cm)	334.3 \pm 87.8 (157.0–514.0)	349.9 \pm 94.0 (216.5–552.5)	358.2 \pm 104.9 (206.5–544.5)	377.2 \pm 88.3 (238.0–589.0)
Nonoperative limb (cm)	390.6 \pm 91.1 (195.5–534.0)	409.0 \pm 92.5 (204.5–602.0)	438.3 \pm 88.1 (240.0–604.5)	431.0 \pm 89.4 (240.5–618.5)
Limb symmetry index (%)	85.8 \pm 12.1 (54.2–106.1)	85.8 \pm 12.9 (58.2–112.5)	80.9 \pm 12.6 (48.4–93.2)	87.7 \pm 9.7 (69.2–99.0)
Overall combination of hops: limb symmetry index (%)	84.7 \pm 13.1 (41.8–98.9)	83.6 \pm 10.6 (52.9–100.8)	80.6 \pm 11.3 (55.4–92.1)	88.2 \pm 7.9 (72.1–98.1)
Lower Extremity Functional Scale	67.4 \pm 11.2 (24–79)	67.1 \pm 10.6 (28–79)	64.9 \pm 11.4 (26–78)	69.6 \pm 10.4 (30–80)

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Effects of Functional Stabilization Training on Pain, Function, and Lower Extremity Biomechanics in Women With Patellofemoral Pain: A Randomized Clinical Trial



● **STUDY DESIGN:** Randomized clinical trial.

● **OBJECTIVES:** To compare the effects of functional stabilization training (FST) versus standard training on knee pain and function, lower-limb and trunk kinematics, trunk muscle endurance, and eccentric hip and knee muscle strength in women with patellofemoral pain.

● **BACKGROUND:** A combination of hip- and knee-strengthening exercise may be more beneficial than quadriceps strengthening alone to improve pain and function in individuals with patellofemoral pain. However, there is limited evidence of the effectiveness of these exercise programs on the biomechanics of the lower extremity.

● **METHODS:** Thirty-one women were randomized to either the FST group or standard-training group. Patients attended a baseline assessment session, followed by an 8-week intervention, and were reassessed at the end of the intervention and at 3 months after the intervention. Assessment measures were a 10-cm visual analog scale for pain, the Lower Extremity Functional Scale, and the single-leg triple-hop test. A global rating of change scale was used to measure perceived improvement. Kinematics were assessed during the single-leg squat. Outcome measures also included trunk endurance and eccentric hip and knee muscle strength assessment.

● **RESULTS:** The patients in the FST group had less pain at the 3-month follow-up and greater global improvement and physical function at the end of the intervention compared to those in the standard-training group. Lesser ipsilateral trunk inclination, pelvis contralateral depression, hip adduction, and knee abduction, along with greater pelvis anteversion and hip flexion movement excursions during the single-leg squat, were only observed in the FST group after the intervention. Only those in the FST group had greater eccentric hip abductor and knee flexor strength, as well as greater endurance of the anterior, posterior, and lateral trunk muscles, after training.

● **CONCLUSION:** An intervention program consisting of hip muscle strengthening and lower-limb and trunk movement control exercises was more beneficial in improving pain, physical function, kinematics, and muscle strength compared to a program of quadriceps-strengthening exercises alone.

● **LEVEL OF EVIDENCE:** Therapy, level 2b-. *J Orthop Sports Phys Ther* 2014;44(4):240-251. Epub 25 February 2014. doi:10.2519/jospt.2014.4940

● **KEY WORDS:** anterior knee pain, biomechanics, hip muscles, patella, stabilization training

Patellofemoral pain (PFP) is one of the most common knee disorders in athletes.⁴⁴ Females have a higher risk of developing this condition,⁷ and up to 10% of young individuals

who initiate a physical activity program will be diagnosed with PFP.⁵¹ Although PFP was originally described as having a self-limiting course, more recent research has shown that a history of this condition may increase the risk of developing patellofemoral osteoarthritis,⁴⁵ suggesting that patients with PFP should be treated to prevent joint degeneration.

The conservative treatment of PFP has traditionally focused on etiological factors local to the patellofemoral joint and addressed poor tracking of the patella inside

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the trochlear groove.⁶ While some studies have suggested that quadriceps-strengthening exercises may help to improve knee pain,^{9,24,50} a recent systematic review¹⁰ and the recent summary from the most recent International PFP Research Retreat³⁹ have concluded that multimodal treatments that address factors proximal to the patellofemoral joint in addition to quadriceps strengthening are preferred to improve pain in individuals with PFP.

Factors proximal to the patellofemoral joint, such as weakness of muscles around the hip and abnormal hip and trunk movements, may play a role in the development of PFP.^{37,38} There is strong evidence that individuals with PFP have weakness of the hip muscles compared to healthy controls.⁴⁰ Studies have also shown that individuals with PFP have less trunk side-flexion strength.^{11,47} In addition, individuals with PFP have demonstrated increased hip adduction^{32,46,47} and medial rotation,^{32,42} as well as increased ipsilateral trunk inclination excursions,^{31,32} during functional tasks. These altered movements have been associated with weakness of the hip abductor, lateral rotator, and extensor muscles^{1,15,43} and are thought to lead to greater knee valgus angle and, consequently, greater pressure on the lateral side of the patellofemoral joint. Finally, it has been suggested that patients with PFP may perform weight-bearing activities with minimal hip flexion and forward trunk lean,³⁷ leading to greater demands on the quadriceps muscle⁵ and, consequently, greater patellofemoral joint stresses.

Several studies have investigated the effectiveness of interventions targeting trunk and hip impairments in this population.^{17,20,21,28,33} One study reported that patients treated with hip-strengthening exercises demonstrated less pain and greater function than patients who did not perform exercises.²⁸ Other studies demonstrated better results when treatment combined hip- and quadriceps-strengthening exercises compared to quadriceps strengthening in isolation.^{20,21,33} Though it has been suggested that improvements

in pain and function in individuals treated with hip-strengthening exercises may be attributed to improvement of lower-limb and trunk movement control and eccentric hip strength,^{20,21,33} the evidence to support these suggestions is limited. To our knowledge, the influence of hip-strengthening exercises on lower-limb kinematics has only been assessed in 1 case series,¹⁷ and only 1 small randomized clinical trial³³ has investigated the effects of this training on eccentric strength of the hip musculature.

Although patients with PFP demonstrate impaired lower-limb and trunk movement control along with hip and trunk muscle weakness, there are limited data on the biomechanical outcomes of rehabilitation programs focused on improving these impairments. A comprehensive biomechanical analysis may determine the factors associated with the success of programs that include hip-strengthening exercises. The purposes of this study were to compare a treatment focused on hip-muscle strengthening and lower-limb and trunk movement control (functional stabilization training [FST]) to a treatment focused primarily on quadriceps strengthening (standard training [ST]) by their effects on knee pain and function, lower-limb and trunk kinematics, trunk muscle endurance, and eccentric hip and knee strength. We hypothesized that, compared to the ST group, the FST group would show greater improvement in pain and function, lower-limb and trunk kinematics, trunk muscle endurance, and eccentric hip and knee strength.

METHODS

A RANDOMIZED, COMPARATIVE-CONTROLLED, single-blinded study was performed at the Laboratory of Intervention and Assessment in Orthopedics and Traumatology of the São Carlos Federal University. Patients were recruited through flyers posted in the university physical therapy clinic between March and November 2012. Potential volunteers were screened, and eligible patients

attended a baseline assessment, followed by a 2-month intervention. Participants were assessed at baseline, at the end of the intervention, and at 3 months after the intervention. All patients read and signed an informed consent form approved by the São Carlos Federal University Ethics Committee for Research on Human Subjects.

Patients

Thirty-one recreational female athletes between 18 and 30 years of age with PFP were randomly assigned to ST ($n = 16$) or FST ($n = 15$) (**FIGURE**). A recreational athlete was defined as anyone participating in aerobic or athletic activity at least 3 times per week for at least 30 minutes. The primary outcome measure was pain intensity measured at the end of the 2-month intervention. Thirty patients (15 in each group) were needed to provide 84% power, based on a 1-sided test, type I error of .05, standard deviation of 1.8 (from prior data), and the ability to detect a 2-cm between-group difference in pain intensity based on a 10-cm visual analog scale (VAS).³³

Patients were included in the study if they were female and had anterior knee pain of 3 or greater on the 10-cm VAS^{11,43} for a minimum of 8 weeks before assessment. Additional inclusion criteria were anterior or retropatellar knee pain during at least 3 of the following activities—ascending/descending stairs, squatting, running, kneeling, jumping, and prolonged sitting—and an insidious onset of symptoms unrelated to trauma.³² Patients were excluded if they had intra-articular pathology; involvement of cruciate or collateral ligaments; patellar instability; Osgood-Schlatter or Sinding-Larsen-Johansson syndrome; hip pain; knee joint effusion; previous surgery in the lower limb; or if palpation of the patellar tendon, iliotibial band, or pes anserinus tendons reproduced the pain.^{11,32}

Randomization

Randomization was performed in blocks of 4. Consecutively numbered, opaque

envelopes were prepared ahead of time and randomly assigned by a computer-generated table of random numbers. A person blinded to information about the patients performed the randomization and provided the group assignment to the treating physical therapist. Randomization was performed after the baseline assessment, and the patients were blinded to group allocation by ensuring that they were unaware of the exercises performed by the other group and by delivering interventions separately to members of each treatment group.

Outcome Measures

At baseline and at the end of the 2-month intervention, the patients completed self-report questionnaires; functional, isokinetic, and trunk endurance tests; and a lower extremity kinematics evaluation. At the follow-up assessment, 3 months after the end of the intervention, only the self-reported questionnaires were completed. All assessments were conducted for the most affected side, which was operationalized as the most painful knee, according to the patient's perception. All kinematics and isokinetic assessments were performed by the first and third authors, who had at least 4 years of experience in these procedures. Only the third author was blind to group allocation, because the first author provided all treatments for both groups. The first author was also responsible for the administration of the questionnaires and the functional and trunk endurance tests.

Pain Pain intensity, the primary outcome measure, was assessed as the worst knee pain experienced in the previous week using a 10-cm VAS, with 0 indicating no pain and 10 indicating extremely intense pain. This pain scale has been shown to be reliable, valid, and responsive in assessing individuals with PFP.¹²

Function Physical function was measured with a self-report questionnaire and a performance-based test. The Lower Extremity Functional Scale (LEFS) is a 20-item questionnaire that rates the

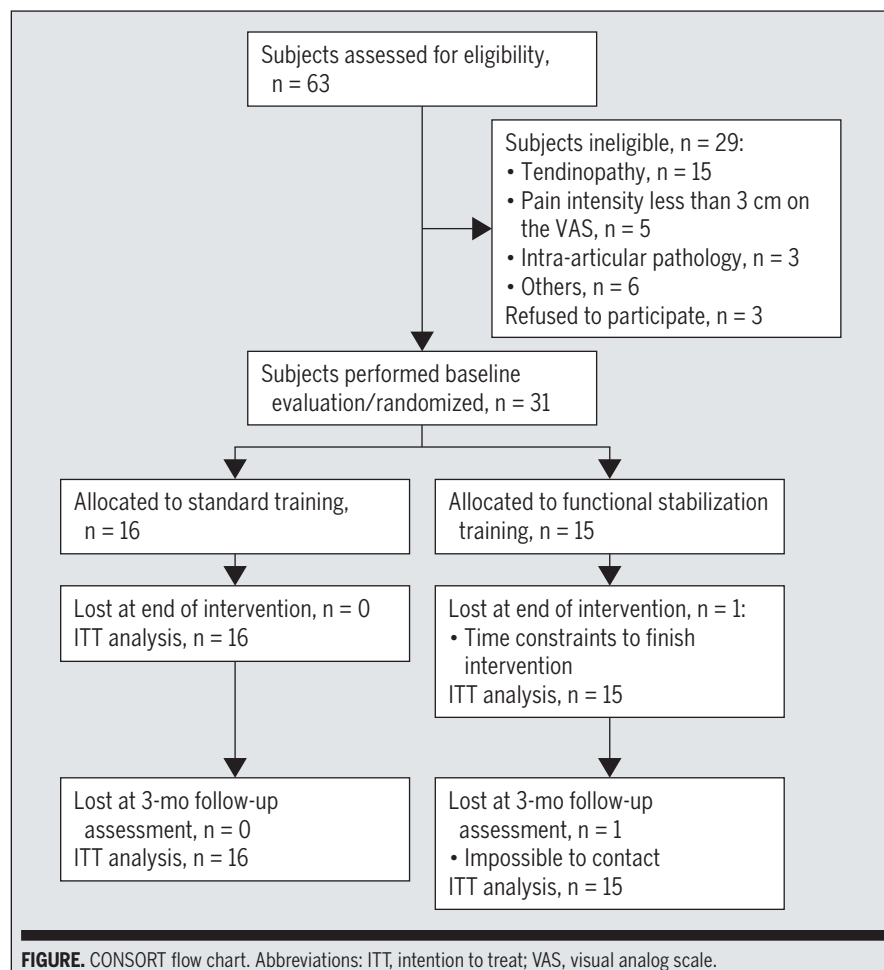


FIGURE. CONSORT flow chart. Abbreviations: ITT, intention to treat; VAS, visual analog scale.

difficulty of performing functional tasks from 0 (extreme difficulty) to 4 (no difficulty). The maximum possible score of 80 indicates good lower extremity function. This scale shows high test-retest reliability, adequate validity, and is responsive to change in individuals with PFP.⁴

Once all self-report measures were completed, the single-leg triple-hop (SLTH) test for distance was performed. For this test, patients jumped 3 consecutive times on the affected limb, covering the greatest distance possible, while keeping their arms behind their back during the test. Patients performed 1 submaximal- and 1 maximal-effort trial, with a 1-minute rest between them, to familiarize themselves with the test. Subsequently, after a 2-minute rest, the patients performed 2 maximal-effort trials with a 2-minute rest between them. The test

was repeated if patients used their arms for propulsion or lost balance during the test. The longest distance jumped (in meters) of the 2 maximum-effort trials was used in the statistical analyses. A previous study has shown excellent reliability for this test, with an intraclass correlation coefficient ($ICC_{3,1}$) and a standard error of measurement (SEM) of 0.92 and 0.15 m, respectively.²

Global Improvement The global rating of change (GRC) scale is a 15-point, single-item scale that measures the patient's impression of improvement in health status following treatment.²⁷ This scale is scored from -7 (a very great deal worse) to +7 (a very great deal better). For this study, the reference criterion of treatment success was a score of +4 (moderately better) or higher.¹³ Data for the GRC scale were collected at the end of the 2-month in-

tervention and at the 3-month follow-up assessment.

Kinematics Evaluation Trunk and lower-limb kinematics were assessed during the single-leg squat test using the Flock of Birds electromagnetic tracking system (miniBIRD; Ascension Technology Corporation, Shelburne, VT), integrated with the MotionMonitor software (Innovative Sports Training, Inc, Chicago, IL). Before testing, electromagnetic tracking sensors were secured to patients using double-sided adhesive tape (Transpore; 3M, St Paul, MN) over the areas of least muscle mass—the sternum, sacrum, mid-lateral thighs (1 sensor in each thigh), and medial to the tibial tuberosity—to minimize potential sensor movement. The kinematics data were collected at a sampling rate of 90 Hz.

Before testing, the medial and lateral malleoli and femoral epicondyles were digitized to determine the ankle and knee joint centers, respectively. The hip joint center was estimated using the functional approach described elsewhere.²⁹ The C7-T1, T12-L1, and L5-S1 interspaces were also digitized, and the trunk angles were designated by the sternal and sacral sensors. An anatomical frame was recorded with the patients standing on the affected lower limb, with the contralateral lower limb off the floor and the knee at 90° of flexion, the hip in neutral position, and the arms crossed in front of the thorax.

Patients were then asked to perform the single-leg squat from the static position to at least 60° of knee flexion, then to return to the starting position. The execution time of the single-leg squat was standardized at 2.0 ± 0.3 seconds, controlled by a progressive digital stopwatch. Each patient performed 3 trials to become familiar with the exercise, then 5 trials for data analysis, with a 1-minute rest between trials. If any of the evaluation requirements were not met or if the patient lost balance during the movement, the trial was disregarded and repeated. The average values obtained from 5 acceptable trials were used for the statistical analyses.

Kinematics data were filtered using a fourth-order, zero-lag, low-pass Butterworth filter at 6 Hz.³² The Euler angles were calculated using the joint coordinate system definitions recommended by the International Society of Biomechanics (using the MotionMonitor software).^{22,52} The kinematics variables monitored in the frontal plane were trunk ipsilateral/contralateral inclination, pelvis contralateral elevation/depression, hip adduction/abduction, and knee adduction/abduction. In the sagittal plane, the variables of interest were trunk flexion/extension, pelvis anteversion/retroversion, and hip flexion/extension. Pelvis movement angles were calculated using the laboratory frame, and the other angles were calculated using the subject frame. The variables represented the movement excursions, which were calculated by subtracting the values acquired when the knee was at 60° of flexion during the single-leg squat from those acquired in the static position. A previous study observed excellent reliability for this movement-analysis protocol, with an ICC_{3,1} ranging from 0.92 to 0.95 and an SEM ranging from 0.07° to 1.83°.³²

Trunk Muscle Endurance Trunk muscle endurance was assessed as the time a patient was able to hold a predefined static position. The 3 tests were conducted in a random order. The endurance of the posterior trunk muscles was assessed with the patients lying prone, their lower body fixed to the test bench at the knees and hips, and holding the trunk horizontal to the floor with their arms held across the chest.³⁰ Endurance of the anterior trunk muscles was assessed with the patient holding the body in a straight line, supported only by both forearms and feet (front plank position).¹⁶ Endurance of the lateral trunk muscles was quantified with the patient holding the body in a straight line, while supported only by 1 forearm and the feet (sideplank position).³⁰ The arm used for support was the arm of the involved side, whereas the arm of the uninvolved side was held next to the trunk. All tests were terminated

when the patient was no longer able to sustain the test position. A single trial for each position was performed, with a 2-minute rest interval between positions. The duration (in seconds) for which the patient held the test position was used for statistical analyses. Reliability of these tests has been reported to be excellent, with an ICC_{3,1} ranging from 0.95 to 0.99 and an SEM ranging from 3.40 to 9.93 seconds.^{16,30}

Strength Evaluation Eccentric function of the musculature was selected for assessment because of its role in controlling lower-limb movement during weight-bearing activities. Eccentric strength of the hip and knee musculature was quantified in random order, using an isokinetic dynamometer (Biodex Multi-Joint System 2; Biodex Medical Systems, Inc, Shirley, NY). The assessment was completed 48 to 96 hours after the trunk muscle endurance evaluation. The hip abductors and adductors were tested with the patients in sidelying on the uninvolved side. The evaluated hip was placed in neutral alignment in all 3 planes, whereas the contralateral hip and knee were flexed and fixed with straps. The trunk was also stabilized using a belt proximal to the iliac crest. The axis of the dynamometer was aligned with the hip joint center, and the resistance arm of the dynamometer was attached to the lateral aspect of the thigh being tested, 5 cm above the base of the patella. The range of motion of the test was from 0° (neutral) to 30° of hip abduction.²

For the hip medial and lateral rotators, patients were in a sitting position, with their knees and hips flexed at 90° and the hip of the tested limb placed at 10° of medial rotation. The rotational axis of the dynamometer was aligned with the center of the patella, and the resistance arm was attached 5 cm above the lateral malleolus. The thigh of the test leg and the trunk were stabilized by straps. The range of motion of this test was from 10° of hip medial rotation to 20° of hip lateral rotation. The angular speed for both hip evaluations was 30°/s.²

The knee extensors and flexors were tested with the patients in a sitting position, with the knees and hips flexed at 90°. The rotational axis of the dynamometer was aligned with the lateral epicondyle of the femur, and the resistance arm was attached 5 cm above the lateral malleolus. Stabilization of the patients was identical to that described above. The range of motion of the test was from 90° to 20° of knee flexion, and the angular speed of the test was 60°/s.²

For familiarization, the patients performed 5 submaximal- and 2 maximal-effort reciprocal eccentric contractions. After a 3-minute rest, the patients performed 2 series of 5 maximal-effort repetitions, with a 3-minute rest between each series. Verbal encouragement was provided to motivate the patients to produce maximum torque. To correct for the influence of gravity on the torque data, the limb was weighed prior to each test, according to the instruction manual for the dynamometer. For the statistical analyses, the highest peak torque value from either the first or second series was selected and normalized by body mass (Nm/kg). These tests have previously been shown to have excellent reliability, with an ICC_{3,1} ranging from 0.78 to 0.97 and an SEM ranging from 0.07 to 0.16 Nm/kg.²

Interventions

The treatment program started 3 to 5 days after baseline isokinetic assessment. Patients from both groups performed the training protocol 3 times per week for 8 weeks, with at least 24 hours between intervention sessions. Neither of the patient groups were assigned home exercise programs. The duration of each session for those in the FST group ranged between 90 and 120 minutes, and for those in the ST group between 75 and 90 minutes. All sessions were supervised by the same physical therapist. During the first 2 weeks of intervention, the patients were asked not to perform physical activities that could cause knee pain. For both groups, the initial loads in most of

TABLE 1			PATIENT DEMOGRAPHICS AT BASELINE	
	Stabilization Group (n = 15)		Standard Group (n = 16)	
Age, y	22.7 ± 3.2		21.3 ± 2.6	
Height, m	1.66 ± 0.1		1.60 ± 0.1	
Mass, kg	57.1 ± 8.2		58.3 ± 7.3	
Body mass index, kg/m ²	20.6 ± 2.0		22.3 ± 2.5	
Symptom duration, mo	60 (3-156)		27 (3-180)	
*Values are mean ± SD except for symptom duration, which is median (range).				

the strengthening exercises were based on a 1-repetition maximum, with pain no higher than 3/10. The 1-repetition maximum was repeated at the beginning of weeks 3 and 6. The loads were progressed when the patients could perform the whole exercise without (1) exacerbation of knee pain, (2) excessive fatigue, and (3) local muscle pain 48 hours after the previous training session.

Standard Training The ST consisted of stretching, as well as traditional weight-bearing and non-weight-bearing exercises emphasizing quadriceps strengthening.^{33,50} A detailed description of the exercises, along with their progression, is provided in **APPENDIX A** (available online).

Functional Stabilization Training The FST was similar to that described by Baldon et al,² with few modifications. The main objective of the first 2 weeks of training was to enhance motor control of the trunk and hip muscles. For the subsequent 3 weeks, the main objectives were to increase strength of the trunk and hip muscles and to continue to improve motor control using weight-bearing activities. In this phase, patients were also taught how a dynamic lower-limb misalignment could contribute to increased patellofemoral stress and knee pain. In the final 3 weeks of training, the difficulty of the exercises was increased and the patients were constantly educated to perform the functional exercises with the lower extremities in neutral frontal plane alignment and to avoid quadriceps dominance by leaning the trunk forward, with hinging at the hips. A detailed de-

scription of the exercises, along with their progression, is provided in **APPENDIX B** (available online).

Statistical Analysis

Normality and variance homogeneity of data were tested using the Shapiro-Wilk and Levene tests, respectively. Data for normally distributed variables were reported as mean and standard deviation, and data for variables that were not normally distributed were reported as median and range. The effects of intervention on the outcome measures were assessed by repeated-measures analysis of variance. The outcomes of pain and function (LEFS and SLTH) were analyzed with a 2-by-3 analysis of variance, with group (FST and ST) as the independent factor and time (baseline, postintervention, and 3 months postintervention) as the repeated factor. The kinematics, trunk endurance, and strength outcome data (collected only at baseline and at the end of the intervention) were analyzed with a 2-by-2 analysis of variance (2 groups and 2 time points). Separate models were used for each outcome measure. When significant group-by-time interactions were found, planned pairwise comparisons with paired *t* tests were used to determine whether the FST or ST group had changed over time, and independent *t* tests were used to determine between-group differences at follow-ups. In the absence of a significant interaction term, the main effects of time and group were reported. Chi-square tests were performed to compare the percentage of patients who perceived moderate

TABLE 2

EFFECT OF TRAINING ON PAIN, PHYSICAL FUNCTION, AND GLOBAL IMPROVEMENT USING INTENTION-TO-TREAT ANALYSIS*

	Baseline	End of Intervention	3-mo Follow-up	Within-Group Change Score at End of Intervention [†]	Within-Group Change Score at 3-mo Follow-up [†]	Between-Group Difference in Change Score at End of Intervention [‡]	Between-Group Difference in Change Score at 3-mo Follow-up [‡]
Worst pain in the previous week (0-10 cm)						-2.2 (-3.7, -0.7)	-2.1 (-4.2, 0.0)
ST	6.1 ± 1.8	3.1 ± 3.2 [§]	2.5 ± 2.7 [§]	-3.0 ± 2.4 (-1.8, -4.3)	-3.6 ± 3.3 (-1.8, -5.4)		
FST	6.6 ± 1.1	1.4 ± 1.4 [§]	0.9 ± 1.5 [§]	-5.2 ± 1.6 (-4.4, -6.1)	-5.7 ± 2.3 (-4.5, -6.7)		
Lower Extremity Functional Scale (0-80)						5.9 (-1.6, 13.4)	6.7 (-0.2, 13.6)
ST	57.6 ± 7.2	70.6 ± 8.0	70.4 ± 8.4	12.9 ± 7.5 (8.9, 17.0)	12.7 ± 6.2 (9.5, 16.0)		
FST	55.4 ± 12.8	74.3 ± 4.6	74.9 ± 3.9	18.9 ± 12.5 (12.0, 25.8)	19.5 ± 11.9 (12.8, 26.1)		
Single-leg triple hop, cm						33.9 (12.0, 55.7)	...
ST	325.1 ± 82.4	330.1 ± 72.5	...	5.0 ± 31.3 (-11.6, 21.7)	...		
FST	336.4 ± 34.8	375.3 ± 48.3 [§]	...	38.9 ± 28.1 (23.3, 54.4)	...		
Global rating of change, percent of patients at least moderately better [¶]						25%	23%
ST	...	75% (12/16)	69% (11/16)		
FST	...	100% (14/14)	92% (12/13)		

Abbreviations: FST, functional stabilization training; ST, standard training.

*Values are mean ± SD unless otherwise indicated.

†Values in parentheses are 95% confidence interval.

‡FST group - ST group.

§Statistically different from baseline ($P < .05$).||Statistically significant between-group difference at this time point ($P < .05$).

¶Values are the percent of patients who answered at least +4 on the global rating of change scale (-7 to +7) by the number of all patients in the group. The fraction of these patients per group sample size is given in parentheses.

improvement in each group, based on the GRC scale. An intention-to-treat analysis was performed using the multiple-imputation method to impute values for all missing data.⁴¹ An analysis using only the patients with complete data was also performed (per-protocol analysis). The statistical analyses were performed using SPSS Version 21 statistical software (SPSS Inc, Chicago, IL). An alpha level of .05 was established for all statistical tests.

RESULTS

Baseline Characteristics

TABLE 1 SUMMARIZES THE DEMOGRAPHIC characteristics of the groups. Two participants dropped out of the FST group, one during the intervention period and another after the intervention. Consequently, there were 30 patients in the postintervention as-

essment and 29 patients in the 3-month postintervention follow-up assessment (FIGURE). The results of the per-protocol analysis (not shown) were consistent with the intention-to-treat analysis.

Pain, Function, and Global Improvement

There was a significant group-by-time interaction for pain ($F_{2,58} = 3.38$, $P = .04$). Planned pairwise comparisons showed that the patients in both groups had less pain at the end of the intervention ($P < .001$) and at the 3-month follow-up ($P < .001$) than at baseline. In addition, patients in the FST group had less pain compared to the ST group at the end of the intervention ($P = .06$) and at the 3-month follow-up ($P = .04$).

The group-by-time interaction term for the LEFS scores was near the threshold of statistical significance ($F_{2,58} = 2.70$, $P = .07$). But there was a significant main

effect of time ($F_{2,58} = 68.60$, $P < .001$), with patients, regardless of group, having a greater LEFS score at the end of the intervention (mean difference, 15.8 points; 95% confidence interval [CI]: 11.7, 19.7) and at the 3-month postintervention follow-up (mean difference, 16.0 points; 95% CI: 12.4, 19.6) compared to baseline scores.

There was a significant group-by-time interaction for the SLTH test ($F_{1,29} = 10.00$, $P < .001$). Only the patients in the FST group had higher values on this functional test at the end of the intervention compared to baseline ($P < .001$). Similarly, patients in the FST group hopped a greater distance when compared to those in the ST group at the end of the intervention ($P = .04$).

Finally, based on the GRC, 25% more patients in the FST group compared to the ST group met the threshold for

TABLE 3

EFFECT OF TRAINING ON LOWER-LIMB AND TRUNK KINEMATICS DURING THE SINGLE-LEG SQUAT USING INTENTION-TO-TREAT ANALYSIS*

	Baseline	End of Intervention	Within-Group Change Score [†]	Between-Group Difference in Change Score (FST – ST Group) [‡]
Sagittal plane, deg				
Trunk extension (+)/flexion (–)				–2.5 (–6.1, 1.0)
ST	–3.0 ± 6.7	–3.7 ± 5.5	–0.7 ± 3.3 (–2.5, 1.0)	
FST	–0.9 ± 7.8	–4.1 ± 9.4	–3.3 ± 6.0 (–6.6, 0.1)	
Pelvis anteversion (+)/retroversion (–)				10.3 (4.2, 16.3)
ST	13.1 ± 6.5	11.2 ± 8.3 [‡]	–1.9 ± 4.8 (–4.4, 0.6)	
FST	16.4 ± 8.9	24.7 ± 9.3 [§]	8.4 ± 10.9 (2.3, 14.4)	
Hip flexion (+)/extension (–)				16.4 (6.3, 26.6)
ST	46.9 ± 9.3	45.4 ± 12.3 [‡]	–1.4 ± 7.3 (–5.3, 2.4)	
FST	52.5 ± 14.6	67.5 ± 14.0 [§]	15.0 ± 18.4 (4.8, 25.2)	
Frontal plane, deg				
Trunk ipsilateral (+)/contralateral inclination (–)				–3.1 (–0.6, –5.6)
ST	7.3 ± 3.4	7.5 ± 4.2	0.1 ± 3.3 (–1.6, 1.9)	
FST	9.7 ± 4.1	6.8 ± 2.6 [§]	–3.0 ± 3.4 (–1.1, –4.8)	
Pelvis elevation (+)/depression (–)				3.7 (0.9, 6.4)
ST	–7.3 ± 3.3 [‡]	–7.2 ± 3.0	0.18 ± 3.05 (–1.4, 1.8)	
FST	–11.1 ± 4.4	–7.3 ± 4.4 [§]	3.84 ± 4.47 (1.4 ± 6.3)	
Hip adduction (+)/abduction (–)				–9.6 (–12.7, –6.4)
ST	17.1 ± 4.3 [‡]	15.4 ± 4.6	–1.7 ± 3.7 (–3.7, 0.3)	
FST	23.5 ± 6.2	12.3 ± 6.9 [§]	–11.2 ± 4.7 (–8.6, –13.9)	
Knee adduction (+)/abduction (–)				3.3 (0.3, 6.2)
ST	–11.0 ± 7.2	–10.9 ± 7.4	0.1 ± 4.2 (–2.1, 2.3)	
FST	–12.3 ± 5.2	–9.0 ± 6.3 [§]	3.4 ± 3.7 (1.3, 5.4)	

Abbreviations: FST, functional stabilization training; ST, standard training.

*Values are mean ± SD unless otherwise indicated and represent movement excursions, which were calculated by subtraction of the values acquired when the knee was at 60° of flexion from those recorded in the static standing position.

[†]Values in parentheses are 95% confidence interval.

[‡]Statistically significant between-group difference at this time point ($P < .05$).

[§]Statistically different from baseline ($P < .05$).

treatment success at 2 months ($P = .04$); the difference at the 3-month postintervention follow-up was 23% ($P = .12$) (TABLE 2).

Kinematics

A significant group-by-time interaction was found for trunk ipsilateral/contralateral inclination ($F_{1,29} = 6.58$, $P = .02$), pelvis contralateral elevation/depression ($F_{1,29} = 7.15$, $P = .01$), pelvis anteversion/retroversion ($F_{1,29} = 11.84$, $P = .002$), hip adduction/abduction ($F_{1,29} = 39.56$, $P < .001$), hip flexion/extension ($F_{1,29} = 10.96$, $P = .002$), and knee adduction/abduction ($F_{1,29} = 5.18$, $P = .03$) movement excursions. Planned pairwise com-

parisons indicated that only the patients in the FST group decreased ipsilateral trunk inclination ($P = .004$), contralateral pelvis depression ($P = .005$), hip adduction ($P < .001$), and knee abduction ($P = .004$) movement excursions by the end of the intervention compared to baseline. In addition, only the patients in the FST group showed greater pelvis anteversion ($P = .01$) and hip flexion ($P = .007$) movement excursions after the intervention compared to baseline. Patients in the FST group also had greater pelvis anteversion ($P < .001$) and hip flexion ($P < .001$) movement excursions when compared to the ST group after the intervention (TABLE 3).

Trunk Endurance and Eccentric Muscle Strength

A significant group-by-time interaction was found for the endurance of the posterior ($F_{1,29} = 19.41$, $P < .001$), anterior ($F_{1,29} = 33.71$, $P < .001$), and lateral ($F_{1,29} = 50.76$, $P < .001$) trunk muscles. Planned pairwise comparisons showed that only those in the FST group had greater trunk endurance for all muscles assessed ($P < .001$) by the end of the 8-week intervention. Also, the individuals in the FST group had greater endurance than those in the ST group for all muscles assessed ($P < .001$) at the end of the intervention (TABLE 4).

There was a significant group-by-time interaction for eccentric muscle strength

TABLE 4

EFFECT OF TRAINING ON TRUNK ENDURANCE AND ECCENTRIC TORQUE USING INTENTION-TO-TREAT ANALYSIS*

	Baseline	End of Intervention	Within-Group Change Score [†]	Between-Group Difference in Change Score (FST – ST Group) [‡]
Anterior trunk endurance, s				54.1 (35.1, 73.2)
ST	61.1 ± 42.5	54.9 ± 28.7 [‡]	-6.2 ± 25.0 (-19.5, 71)	
FST	67.5 ± 24.6	115.4 ± 35.9 [§]	47.9 ± 26.9 (33.0, 62.8)	
Lateral trunk endurance, s				29.9 (21.3, 38.5)
ST	32.4 ± 21.6	35.6 ± 24.8 [‡]	3.2 ± 7.3 (-0.7, 71)	
FST	40.3 ± 15.5	73.4 ± 14.1 [§]	33.1 ± 15.0 (24.8, 41.4)	
Posterior trunk endurance, s				48.5 (26.0, 71.0)
ST	86.6 ± 43.8	83.5 ± 36.8 [‡]	-3.1 ± 25.0 (-16.4, 10.2)	
FST	114.4 ± 26.6	159.8 ± 30.2 [§]	45.4 ± 35.7 (25.6, 65.2)	
Eccentric hip abductor torque, Nm/kg				0.2 (0.1, 0.3)
ST	1.2 ± 0.3	1.3 ± 0.3 [‡]	0.0 ± 0.1 (0.0, 0.1)	
FST	1.3 ± 0.2	1.5 ± 0.2 [§]	0.2 ± 0.2 (0.1, 0.3)	
Eccentric hip adductor torque, Nm/kg				0.0 (-0.1, 0.1)
ST	1.8 ± 0.3	1.8 ± 0.3	0.1 ± 0.2 (0.0, 0.1)	
FST	1.8 ± 0.2	1.9 ± 0.2	0.1 ± 0.1 (0.0, 0.1)	
Eccentric hip lateral rotator torque, Nm/kg				0.0 (-0.1, 0.1)
ST	0.7 ± 0.1	0.8 ± 0.1	0.1 ± 0.1 (0.0, 0.1)	
FST	0.8 ± 0.1	0.8 ± 0.1	0.1 ± 0.1 (0.0, 0.1)	
Eccentric hip medial rotator torque, Nm/kg				0.1 (0.0, 0.3)
ST	1.3 ± 0.3	1.3 ± 0.3	0.0 ± 0.2 (-0.1, 0.1)	
FST	1.4 ± 0.2	1.5 ± 0.2	0.1 ± 0.2 (0.0, 0.2)	
Eccentric knee flexor torque, Nm/kg				0.1 (0.0, 0.2)
ST	1.3 ± 0.2	1.3 ± 0.2 [‡]	0.0 ± 0.1 (0.0, 0.1)	
FST	1.3 ± 0.2	1.5 ± 0.1 [§]	0.1 ± 0.1 (0.0, 0.2)	
Eccentric knee extensor torque, Nm/kg				0.2 (-0.1, 0.5)
ST	2.8 ± 0.7	3.1 ± 0.6	0.4 ± 0.4 (0.2, 0.6)	
FST	2.9 ± 0.4	3.4 ± 0.4	0.6 ± 0.5 (0.3, 0.8)	

Abbreviations: FST, functional stabilization training; ST, standard training.

*Values are mean ± SD unless otherwise indicated.

[†]Values in parentheses are 95% confidence interval.

[‡]Between-group difference at this moment ($P < .05$).

[§]Statistically different from baseline ($P < .05$).

of the hip abductors ($F_{1,29} = 9.84$, $P = .004$) and knee flexors ($F_{1,29} = 6.03$, $P = .02$). The group-by-time interaction for the hip medial rotators did not meet the significance threshold ($F_{1,29} = 3.34$, $P = .07$). Only those in the FST group showed greater eccentric hip abductor ($P = .001$) and knee flexor ($P = .004$) strength values after the 8-week intervention. Also, the patients in the FST group had greater eccentric hip abductor ($P = .01$) and knee flexor ($P = .03$) strength values compared to the patients in the ST group after the intervention.

A significant main effect of time (no interaction) was found for the eccentric hip adductor ($F_{1,29} = 4.49$, $P = .04$), hip lateral rotator ($F_{1,29} = 10.94$, $P = .003$), and knee extensor ($F_{1,29} = 36.90$, $P < .001$) muscle strength values. Regardless of group, patients showed greater strength values of the eccentric hip adductor (mean difference, 0.06 Nm/kg; 95% CI: 0.01, 0.12), hip lateral rotator (mean difference, 0.06 Nm/kg; 95% CI: 0.02, 0.10), and knee extensor (mean difference, 0.46 Nm/kg; 95% CI: 0.30, 0.61) muscle strength after the 8-week intervention (TABLE 4).

DISCUSSION

OVERALL, THE RESULTS OF THIS STUDY show that women with PFP who participated in a treatment program that included hip muscle strengthening and lower-limb and trunk movement control exercises experienced greater improvements in pain, physical function, lower-limb and trunk kinematics, trunk muscle endurance, and eccentric strength of the hip and knee musculature compared to women who participated in a treatment program focusing primarily on

quadriceps-strengthening exercises. These results add to the findings of existing studies^{20,21,33} that a comprehensive treatment approach involving trunk-, hip-, and knee-strengthening exercises, along with functional training and feedback on proper dynamic lower-limb alignment, is more effective than a treatment program primarily addressing the knee musculature in this population.

Both groups experienced statistically and clinically important improvements in pain after training, with an average improvement exceeding the minimal clinically important difference (MCID) of 2 cm on the VAS.¹² But it should be noted that the lower bounds of the 95% CIs of the within-group change scores for pain at both postintervention times were greater than 2.0 only for the FST group. In addition, the FST group showed significantly less pain at 3 months after the intervention and a greater treatment success rate at the end of the intervention program compared to the ST group. Although the groups were not significantly different in regard to pain after the end of the intervention period, the between-group differences in change scores were greater than the MCID, and the lower bounds of the 95% CIs did not cross zero, favoring the FST group at both time points. However, the 95% CIs included values that were smaller than the MCID, meaning that the between-group differences may not be clinically significant.

The FST and ST groups also had statistically and clinically important improvements in function after training, as the average improvement in each group was above the MCID value of 9 points on the LEFS questionnaire.⁴ In addition, we only verified a trend for group-by-time interaction effect for this outcome, with small between-group change scores favoring the FST group at both follow-ups. On the other hand, only the FST group had better performance during the SLTH test at the end of the intervention program when compared to baseline and when compared to the ST group after intervention. This discrepancy between

the results of the LEFS and SLTH may be due to the LEFS underrepresenting activities that are limited by PFP. Several activities listed in the LEFS, such as walking, putting on shoes, performing light activities around the home, standing, and rolling over in bed, are generally not limited by PFP.

The present study also provides innovative evidence that the greater clinical benefits of FST are associated with trunk and lower extremity biomechanical improvements in both the frontal and sagittal planes. In the frontal plane, only those in the FST group had lesser ipsilateral trunk inclination, contralateral pelvis depression, hip adduction, and knee abduction movement excursions, along with greater hip abductor eccentric muscle strength and endurance of the lateral trunk muscles, after the 8-week intervention. These findings are noteworthy, as patients with PFP appear to have excessive ipsilateral trunk inclination,³² contralateral pelvis depression,³² hip adduction,^{31,32,46,47} and knee abduction^{31,32} excursions, characteristics that are believed to increase the Q-angle and stress on the lateral compartment of the patellofemoral joint.²⁵ Several studies have also shown weakness of the hip abductors^{3,8,26,47} and lateral trunk muscles^{11,47} in individuals with PFP. It has been suggested that the weakness of these muscle groups might be related to the frontal plane kinematic alterations often noted in individuals with PFP.^{15,32,47} Thus, the greater eccentric hip abductor muscle strength and lateral trunk endurance observed in the FST group after intervention might have contributed to the enhancement of frontal plane lower-limb movement control and, consequently, to a decrease in patellofemoral stress and pain.

In the sagittal plane, only the FST group showed greater pelvis anteversion and hip flexion excursions, along with greater eccentric knee flexor muscle strength and endurance of the posterior trunk muscles, after intervention. Powers³⁷ has suggested that individuals with PFP might perform weight-bearing ac-

tivities with decreased hip flexion and increased pelvis anteversion and trunk extension, resulting in a posterior shift of the center of mass and increased external knee flexor moment. This pattern of motion has been associated with inhibition of the hip and trunk extensor muscles and greater quadriceps muscle activity,^{5,36} resulting in increased patellofemoral joint compression. In the present study, although the patients in the FST group showed greater pelvis anteversion, this movement was associated with increased hip flexion and no change in the trunk movement excursion. Because movements of the pelvis were calculated with the laboratory frame, the current results demonstrate that the individuals in the FST group performed the single-leg squat after intervention with greater forward trunk lean, shifting their center of mass anteriorly and decreasing the external knee flexor moment. The greater eccentric knee flexor strength and endurance of the posterior trunk muscles resulting from the training might have played an important role in facilitating these kinematics changes. The hamstring muscles are the primary knee flexor muscles but are also important hip extensors.³⁴ Although the strength of the hip extensors was not measured in the current study, the gluteus maximus muscle, which is the primary hip extensor,³⁴ might also have been strengthened in the FST group, as these participants performed several exercises that emphasized this muscle. To perform the single-leg squat with greater hip flexion and anterior trunk lean, the patients in the FST group might have increased the demand on the hip and trunk extensor muscles, simultaneously decreasing the demand on the quadriceps muscle and resulting in less patellofemoral joint compression and pain.

An important clinical aspect of the FST that should be highlighted is the constant feedback provided by the physical therapist about proper lower-limb alignment during the weight-bearing exercises. The patients in the FST group were persistently asked to keep their

lower limb properly aligned in the frontal plane and to avoid quadriceps dominance by maintaining an adequate anterior trunk lean. Study findings have suggested that this approach is critical to influence changes in lower-limb kinematics, and that hip strengthening exercises alone may not be sufficient to alter patterns of motion.^{17,23,49} Earl and Hoch¹⁷ observed that a program focused on strengthening the hip and trunk musculature did not affect lower extremity kinematics in females with PFP. Conversely, Baldon et al² demonstrated that hip-strengthening and functional exercises combined with motor-learning instruction (similar to the current training) increased eccentric hip abductor muscle strength and decreased hip adduction and knee abduction excursions during the single-leg squat in healthy females. Noehren et al³⁵ verified that real-time kinematic feedback aimed at decreasing hip adduction during the stance phase of running decreased hip adduction excursion and knee pain in females with PFP. Because the patients in the FST group received strength and functional training combined with education about lower-limb alignment, we were not able to differentiate the specific components of the training that were responsible for the kinematics changes.

An interesting finding in this study was the nearly statistically significant group-by-time interaction of eccentric hip medial rotator muscle strength that favored the FST group (between-group difference in change score of 0.13 Nm/kg) and the absence of an interaction effect for eccentric hip lateral rotator strength. A possible explanation for these results may be the position in which the hip rotator muscles were evaluated. In an anatomical and computer-modeling study, Delp et al¹⁴ investigated the influence of hip flexion on the rotational moment arms of the hip muscles. It was demonstrated that the gluteus medius and gluteus maximus, which were the primary muscles targeted with the FST, shifted almost completely from lateral rotators to medial rotators when the hip

was flexed at 90°. In our study, given that the hip rotator muscles were evaluated at 90° of hip flexion, it is possible that the strengthening of these muscles contributed to the greater eccentric hip medial rotator muscle strength produced by the FST group after training.

This study has some limitations. First, the small number of patients included in this clinical trial resulted in large 95% CIs, precluding more definitive conclusions. Second, the evaluator was not blinded to group assignment, and this might have introduced measurement bias during the follow-up assessments. To minimize this problem, the evaluator used standardized scripts during testing to deliver consistent instructions. Third, due to the multimodal approach of the FST, the treatment sessions in this group were approximately 30 minutes longer than those in the ST group. Although the greater training volume in the FST group could have induced greater quadriceps strength gains and played a role in the greater improvement in pain and function in this group, this was likely not the case because there was no interaction effect for this dependent variable. Finally, the current findings should not be extrapolated to males with PFP, because only women participated in this study. Several articles have shown that, with weight-bearing activities, healthy females have greater hip adduction and knee abduction movement excursions when compared to males.^{1,18,19,48} It is possible that this faulty lower-limb movement pattern might contribute to the greater incidence of PFP in females. Consequently, improvements in lower-limb kinematics may be more crucial to a successful clinical result in females than in males, although there is still no evidence to support this. Future studies should attempt to verify whether the current findings apply to males with PFP.

CONCLUSION

HIP- AND KNEE-STRENGTHENING EXERCISES associated with verbal feedback on proper lower-limb

alignment during functional activities were more beneficial for women with PFP compared to a treatment focusing primarily on quadriceps strengthening and lower-limb stretching. ●

KEY POINTS

FINDINGS: The FST group experienced less pain at 3 months postintervention and greater global improvement and physical function at the end of the 2-month intervention. Those in the FST group also demonstrated improvement in trunk and lower extremity alignment when performing a single-leg squat after the end of the 2-month intervention.

IMPLICATIONS: Strengthening of the hip abductor, extensor, and lateral rotator muscles, combined with education on proper lower-limb alignment during weight-bearing activities, should be used in females with PFP.

CAUTION: The design of this study does not allow us to determine the mechanisms underlying the improvements in pain and function observed in this study.

ACKNOWLEDGEMENTS: *We gratefully acknowledge the financial support (scholarships) from Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Brazil).*

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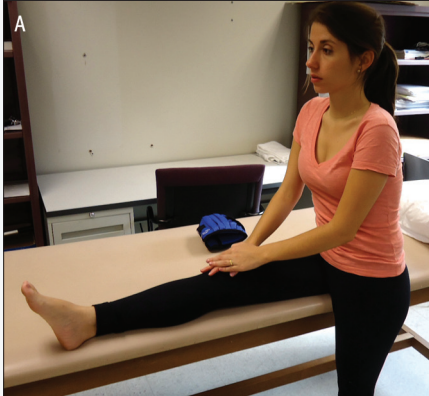
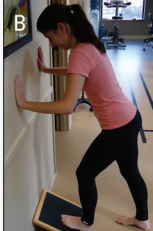


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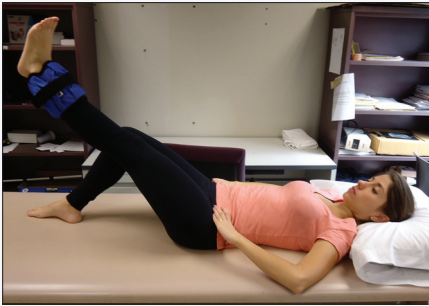



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APPENDIX A



TREATMENT PROTOCOL PERFORMED BY THE SUBJECTS IN THE STANDARD TRAINING GROUP

Exercise/Progression	Description	Illustration
<p>Quadriceps (A) and lateral retinaculum (B) stretches</p> <p>Weeks 1 to 8</p>	<ul style="list-style-type: none"> • These stretches were assisted by the therapist • 3 sets of 30 seconds • Performed with maximum range of motion that the subjects could tolerate 	 
<p>Hamstrings (A), soleus (B), gastrocnemius (C), and iliotibial band (D) stretches</p> <p>Weeks 1 to 8</p>	<ul style="list-style-type: none"> • These stretches were performed individually • 3 sets of 30 seconds • Performed with maximum range of motion that the subjects could tolerate 	   

APPENDIX A

Exercise/Progression	Description	Illustration
<p>Straight leg raise in supine</p> <p>Weeks 1 to 2</p> <p>Weeks 3 to 5</p> <p>Weeks 6 to 8</p>	<ul style="list-style-type: none"> • 2 sets of 20 repetitions • Resistance: ankle weights • Initial load: 50% of 1RM • Exercise progression: increasing 0.5 kg • 3 sets of 12 repetitions • Initial load: 75% of 1RM • Exercise progression: increasing 0.5 kg • As in weeks 3 to 5 	
<p>Seated knee extension (90°-45° of knee flexion)</p> <p>Weeks 1 to 2</p> <p>Weeks 3 to 5</p> <p>Weeks 6 to 8</p>	<ul style="list-style-type: none"> • 2 sets of 20 repetitions • Resistance: weight-training device • Initial load: 50% of 1RM • Exercise progression: increasing 2 to 5 kg • 3 sets of 12 repetitions • Initial load: 75% of 1RM • Exercise progression: increasing 2 to 5 kg • As in weeks 3 to 5 	
<p>Leg press (0°-45° of knee flexion)</p> <p>Weeks 1 to 2</p> <p>Weeks 3 to 5</p> <p>Weeks 6 to 8</p>	<ul style="list-style-type: none"> • 2 sets of 20 repetitions • Resistance: weight-training device • Initial load: 50% of 1RM • Exercise progression: increasing 5 to 10 kg • 3 sets of 12 repetitions • Initial load: 75% of 1RM • Exercise progression: increasing 5 to 10 kg • As in weeks 3 to 5 	
<p>Wall squat (0°-60° of knee flexion)</p> <p>Weeks 1 to 2</p> <p>Weeks 3 to 5</p> <p>Weeks 6 to 8</p>	<ul style="list-style-type: none"> • 2 sets of 20 repetitions, with 5-second isometric contraction • Exercise progression: increasing 2-second hold • 3 sets of 12 repetitions, with 10-second isometric contraction • Resistance: holding weights • Initial load: 10% of body mass • Exercise progression: increasing 5% of body mass • As in weeks 3 to 5 	

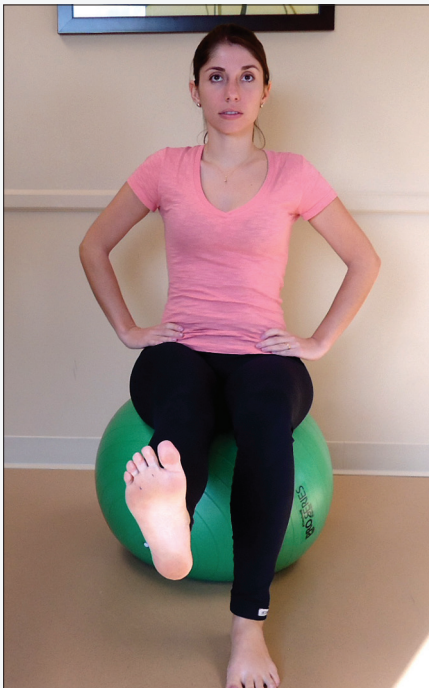

APPENDIX A

Exercise/Progression	Description	Illustration
<p>Step-ups and step-downs from a 20-cm step</p> <p>Weeks 1 to 2</p> <p>Weeks 3 to 5</p> <p>Weeks 6 to 8</p>	<ul style="list-style-type: none"> • Not performed • 3 sets of 12 repetitions • Resistance: holding weights • Initial load: 10% of body mass • Exercise progression: increasing 5% of body mass • As in weeks 3 to 5 	
<p>Single-leg standing on unstable platform</p> <p>Weeks 1 to 2</p> <p>Weeks 3 to 5</p> <p>Weeks 6 to 8</p>	<ul style="list-style-type: none"> • Not performed • Not performed • 3 sets of 30 seconds • Exercise progression: eyes opened to eyes closed 	




Abbreviation: 1RM, 1-repetition maximum.

APPENDIX B



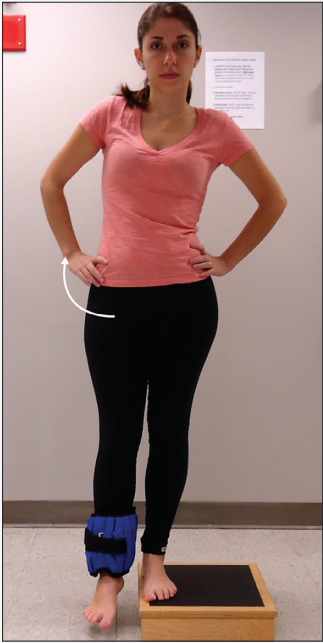
TREATMENT PROTOCOL PERFORMED BY THE SUBJECTS IN THE FUNCTIONAL STABILIZATION TRAINING GROUP

Exercise/Progression	Description	Illustration
Transversus abdominis and multifidus muscle training Weeks 1 to 2	<ul style="list-style-type: none"> • Quadruped and prone (not shown): 2 sets of 15 repetitions, with 10-second isometric cocontraction • Sitting on the Swiss ball: 5 repetitions with 20-second isometric cocontraction • Exercise progression: increasing 5-second hold 	
Weeks 3 to 5	<ul style="list-style-type: none"> • Not performed 	
Weeks 6 to 8	<ul style="list-style-type: none"> • Not performed 	
Lateral bridge (A) and ventral (B) bridge Weeks 1 to 2	<ul style="list-style-type: none"> • Not performed 	
Weeks 3 to 5	<ul style="list-style-type: none"> • 5 sets of 30 seconds • Exercise progression: increasing 5-second hold • Exercises performed with knee support (not shown) 	
Weeks 6 to 8	<ul style="list-style-type: none"> • 5 sets of 45 to 60 seconds • Exercise progression: increasing 5-second hold • Exercises performed with foot support 	

APPENDIX B

Exercise/Progression	Description	Illustration
Trunk extension on the Swiss ball		
Weeks 1 to 2	<ul style="list-style-type: none"> Not performed 	
Weeks 3 to 5	<ul style="list-style-type: none"> 3 sets of 12 repetitions Exercise progression: increasing 2 repetitions Performed with the arms crossing the thorax (not shown) 	
Weeks 6 to 8	<ul style="list-style-type: none"> 3 sets of 12 repetitions Exercise progression: increasing 2 repetitions Performed with the hands behind the neck 	
Isometric hip abduction/lateral rotation in standing		
Weeks 1 to 2	<ul style="list-style-type: none"> 2 sets of 20 repetitions, with 5-second isometric contraction Exercise progression: increasing 2-second hold Hip flexion and forward trunk lean were emphasized 	
Weeks 3 to 5	<ul style="list-style-type: none"> Not performed 	
Weeks 6 to 8	<ul style="list-style-type: none"> Not performed 	
Hip abduction/lateral rotation/extension in sidelying		
Weeks 1 to 2	<ul style="list-style-type: none"> 2 sets of 20 repetitions, with 5-second isometric contraction Resistance: ankle weight Initial load: 20% of 1RM Exercise progression: increasing 0.5 kg 	
Weeks 3 to 5	<ul style="list-style-type: none"> 3 sets of 12 repetitions Initial load: 75% of 1RM Exercise progression: increasing 0.5 kg 	
Weeks 6 to 8	<ul style="list-style-type: none"> As in weeks 3 to 5 	

APPENDIX B

Exercise/Progression	Description	Illustration
<p>Hip extension/lateral rotation in prone</p> <p>Weeks 1 to 2</p> <p>Weeks 3 to 5</p> <p>Weeks 6 to 8</p>	<ul style="list-style-type: none"> • 2 sets of 20 repetitions, with 5-second isometric contraction • Resistance: ankle weight • Initial load: 20% of 1RM • Exercise performed with the knee at 90° of knee flexion (not shown) • Exercise progression: increasing 0.5 kg • 3 sets of 12 repetitions • Initial load: 75% of 1RM • Exercise progression: increasing 0.5 kg • As in weeks 3 to 5 	
<p>Hip abduction/lateral rotation with slight knee and hip flexion in sidelying</p> <p>Weeks 1 to 2</p> <p>Weeks 3 to 5</p> <p>Weeks 6 to 8</p>	<ul style="list-style-type: none"> • 2 sets of 20 repetitions, with 5-second isometric contraction • Resistance: elastic band • Initial load: 2 elastic resistance levels lower than the 1RM • Exercise progression: increasing 1 elastic resistance level • 3 sets of 12 repetitions • Initial load: 1 elastic resistance level lower than the 1RM • Exercise progression: increasing 1 elastic resistance level • As in weeks 3 to 5 	
<p>Pelvic drop in standing</p> <p>Weeks 1 to 2</p> <p>Weeks 3 to 5</p> <p>Weeks 6 to 8</p>	<ul style="list-style-type: none"> • Not performed • 3 sets of 12 repetitions • Resistance: ankle weight • Initial load: 75% of 1RM • Exercise progression: increasing 1 to 2 kg • As in weeks 3 to 5 	

APPENDIX B

Exercise/Progression

Description

Illustration

Hip lateral rotation in closed kinetic chain

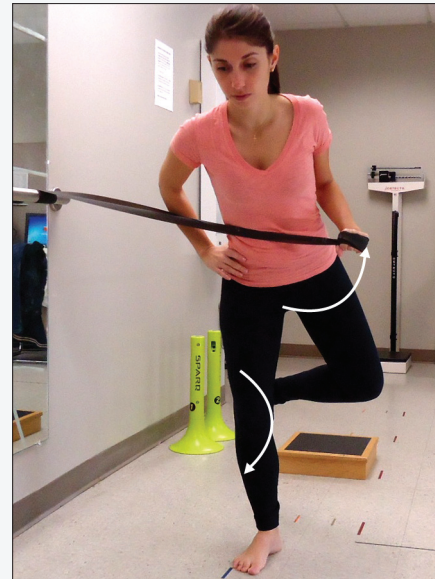
Weeks 1 to 2

Weeks 3 to 5

- Not performed
- 3 sets of 12 repetitions
- Resistance: elastic band
- Initial load: 1 elastic resistance level lower than the 1RM
- Exercise progression: increasing 1 elastic resistance level

Weeks 6 to 8

- As in weeks 3 to 5



Single-leg deadlift

Weeks 1 to 2

Weeks 3 to 5

- Not performed
- 3 sets of 12 repetitions
- Resistance: elastic band
- Initial load: 1 elastic resistance level lower than the 1RM
- Exercise progression: increasing 1 elastic resistance level

Weeks 6 to 8

- As in weeks 3 to 5
- Exercise performed in front of the mirror with elastic resistance around the knee of the support limb to encourage hip abduction and lateral rotation



Single-leg squat

Weeks 1 to 2

Weeks 3 to 5





Weeks 6 to 8

- Not performed
- Not performed
- 3 sets of 12 repetitions
- No load
- Exercise performed in front of the mirror with elastic resistance around the knee of the support limb to encourage hip abduction and lateral rotation
- Hip flexion and forward trunk lean were emphasized



[RESEARCH REPORT]

APPENDIX B

Exercise/Progression	Description	Illustration
Forward lunge		
Weeks 1 to 2	<ul style="list-style-type: none"> • Not performed 	
Weeks 3 to 5	<ul style="list-style-type: none"> • Not performed 	
Weeks 6 to 8	<ul style="list-style-type: none"> • 3 sets of 12 repetitions • No load • Exercise performed in front of the mirror with elastic resistance around the knee of the anterior limb to encourage hip abduction and lateral rotation • Hip flexion and forward trunk lean were emphasized 	
Prone knee flexion		
Weeks 1 to 2	<ul style="list-style-type: none"> • 2 sets of 20 repetitions • Resistance: weight-training device • Initial load: 50% of 1RM • Exercise progression: increasing 1 to 2 kg 	
Weeks 3 to 5	<ul style="list-style-type: none"> • 3 sets of 12 repetitions • Initial load: 75% of 1RM • Exercise progression: increasing 1 to 2 kg 	
Weeks 6 to 8	<ul style="list-style-type: none"> • As in weeks 3 to 5 	
Seated knee extension (90°-45° of knee flexion)		
Weeks 1 to 2	<ul style="list-style-type: none"> • 2 sets of 20 repetitions • Resistance: weight-training device • Initial load: 50% of 1RM • Exercise progression: increasing 2 to 5 kg 	
Weeks 3 to 5	<ul style="list-style-type: none"> • 3 sets of 12 repetitions • Initial load: 75% of 1RM • Exercise progression: increasing 2 to 5 kg 	
Weeks 6 to 8	<ul style="list-style-type: none"> • As in weeks 3 to 5 	
Single-leg standing on unstable platform		
Weeks 1 to 2	<ul style="list-style-type: none"> • 3 sets of 30 seconds • Hip flexion and forward trunk lean were emphasized • Transversus abdominis and multifidus muscle cocontraction 	
Weeks 3 to 5	<ul style="list-style-type: none"> • As in weeks 1 to 2 • External perturbation with medicine ball emphasizing eccentric hip abductor and lateral rotator muscle contraction 	
Weeks 6 to 8	<ul style="list-style-type: none"> • As in weeks 3 to 5 	

Abbreviation: 1RM, 1-repetition maximum.