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Reactive Neuromuscular Training for the Anterior Cruciate Ligament-Deficient Knee: A Case Report

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Objective: To demonstrate the response to a proprioceptive training model during a 1-week rehabilitation regime. The techniques were demonstrated on a college-aged female basketball player who had injured her anterior cruciate ligament (ACL) several weeks earlier. The athlete was tested, trained, and then retested during her semester break.

Background: The ACL injury has become a fairly common occurrence in the world of athletics. Knowing this, the athletic trainer is constantly searching for ways to improve the rehabilitative process. New research demonstrates that rehabilitation should be based on proprioception. The ACL not only serves a mechanical role by limiting passive knee mobility but also serves a sensory role through the mechanoreceptors deep in its tissue, which communicate with the neuromuscular system to provide proprioceptive feedback during training and competition.

Differential Diagnosis: Partial or complete tear of the ACL.

Treatment: The athlete was treated with a rehabilitation protocol based on proprioception, which uses reactive neuromuscular training.

Uniqueness: Our rehabilitation focused on the muscular imbalances about the hip, knee, and ankle. The athlete achieved dramatic decreases in muscular imbalances about the hip and knee in only 1 week of rehabilitation through reactive neuromuscular training.

Conclusions: The athlete had significant gains in strength over her brief period of therapy. However, these gains can be viewed only as neuromuscular changes and not strictly as gains in strength. The athlete returned to postseason competition under the supervision of her surgeon, who later recommended surgical reconstruction at the completion of the basketball season with rehabilitation during the offseason.

Key Words: oscillating technique for isometric stabilization, impulse technique for isometric stabilization

The anterior cruciate ligament (ACL) injury is commonly managed by orthopaedic surgeons, physical therapists, and athletic trainers. A variety of surgical techniques and rehabilitation protocols is used to treat the ACL injury. It is important to realize, however, that the partial or complete tear of the ACL is, in most cases, the symptom or result of underlying muscular or mechanical imbalances in the lower extremity. These imbalances can be created by traumatic or microtraumatic injuries and can occur with or without contact. Contact injuries, as the name implies, are the result of a collision with another individual or object. The contact injury has no warning signs and no history of symptoms. Noncontact injuries are sustained without contact or when the momentum or movement of the body exceeds muscular control and joint stability, thus exposing the ligament to stress without the coordinated muscular support of the knee. Many underlying problems may have contributing roles in noncontact ACL injuries and stresses, including muscular imbalances of the hip, poor foot mechanics, poor deceleration and plyometric (energy-storing) function, inefficient quadriceps/hamstring ratio, poor acclimation to playing surface, and poor proprioception.[1-6] The underlying problem must be identified and addressed during rehabilitation if the athlete is to return to participation at the preinjury level.[2-6] With this principle in mind, it is the job of the sports medicine team to find the safest and most efficient path for the athlete that will allow the athlete to return to competition, whether this path is surgical and rehabilitative or strictly rehabilitative. However, the focus must always remain on the cause, not just the symptom.

Remember that not only do structures around the knee joint need to be trained, but other structures in the lower extremity must be trained as well.[1,2,5-8] These structures include the musculature about the hip and ankle joints. Damage to the ACL can affect the whole lower extremity as a result of the mechanical imbalances created by the knee.[1,6,8-10] The mechanical imbalances, which may predate the noncontact injury and hinder the rehabilitation process, lead the body to make muscular compensations in order to function as normally as possible. These compensations will occur and recur since the body will always sacrifice quality of movement for quantity.[1,5]

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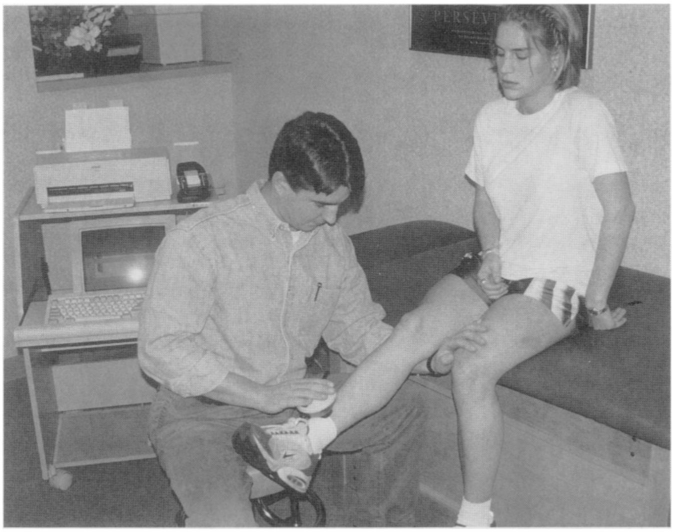

Figure 1. Certified athletic trainer performing computer dynamometer test.

Attention must be given equally in 2 areas that are sometimes overlooked: sport-specific function and motor learning. In order to understand sport-specific function, the clinician must identify the demands of the sport and the abilities of the athlete. Functional exercise programs allow the physical therapist and the athletic trainer to combine conditioning and rehabilitation with activities that increase motor pathway function and reaction time, thus restoring efficient movement through motor programs. An example of this is an exercise program known as reactive neuromuscular training (RNT), first introduced by Voight and Cook[5] and the basis for our ACL exercise regime, which emphasizes kinesthetic or proprioceptive input and places less emphasis on verbal and visual input.

REACTIVE NEUROMUSCULAR TRAINING

The theory behind RNT is to emphasize activities designed to minimize the need for verbal and visual instruction from the physical therapist or athletic trainer. This type of training asks only that the athlete respond to a stimulus created by an outside force (eg, being pulled by elastic tubing). The initial emphasis is not on altering strength, but rather on dynamic stability and proprioception, which can be defined as awareness of posture, movement, and changes in equilibrium and the knowledge of position, weight, and resistance of objects in relation to the body, respectively.[11] This type of training focuses on appropriate body positioning and posture to promote proper dynamic muscular stabilization during functional activities, thus allowing for the control of abnormal joint translation during functional activities.[1,5] These activities are designed to emphasize quality of movement before quantity of movement.

The goal of phase I is to successfully stimulate a proprioceptive reaction for a certain number of repetitions. This should not be attempted until active range of motion is restored. If proprioception and stability training are attempted without a good mobility base, then compensations will be learned and motor programs will be altered. However, with a good mobility base, the correct movements will be learned and will become automatic.[1,5]

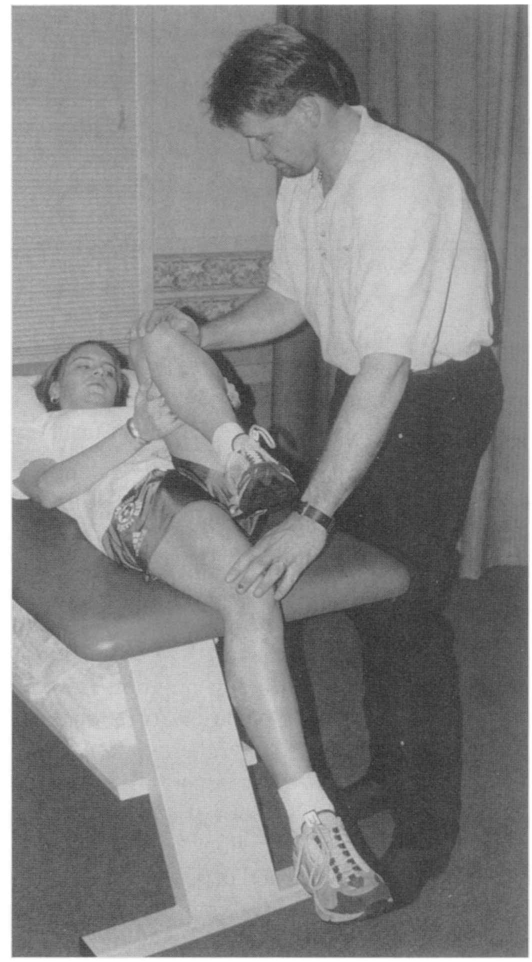

Figure 2. Physical therapist performing modified Thomas Test.

PRESENTATION OF THE CASE

Our subject was an ACL-deficient, college-aged female basketball player. Her rehabilitative training regimen followed a progression adapted from the theory of RNT. The athlete began her rehabilitative program with her collegiate certified athletic trainer before her visit to our clinic. The collegiate athletic trainer had succeeded in helping her regain full, active range of motion and basic strength; however, her ballistic movements were awkward.

We were asked by her collegiate athletic trainer to evaluate and treat her over the semester break. The athlete already had a solid rehabilitation foundation before she began her work with us due to her program with her collegiate athletic trainer. We will focus only on the particular treatment we provided in our clinic and the results we achieved over the athlete's semester break.

Table 1. Computer Dynamometer Test Comparing Right and Left Lower Extremities, December 19 (Refer to Table 7)

	Left (kg)	Right (kg)	Deficit (%)
Hip medial rotation	13.61	8.16	−40 R*
Hip adduction	24.49	19.96	−18 R
Knee flexion (lateral rotation)	16.78	13.61	−19 R
Knee extension	26.76	21.77	−19 R

* R, right leg (the involved side).

The athlete was injured during a basketball game on November 7. She reported that her knee twisted and she felt a "pop." The initial evaluation by the orthopaedist revealed substantial instability and a positive Lachman from a probable ACL tear. The athlete was braced and treated acutely, then allowed to return to activities as tolerated. The goals set by the athlete's orthopaedic surgeon and collegiate athletic trainer were to have the athlete ready for postseason play with the possibility of reconstructive surgery afterward. We were informed that we would have approximately 5 visits to work with the athlete over the holiday season.

The athlete's initial rehabilitation program from her collegiate athletic trainer included a variety of strengthening and conditioning activities. On odd days, her workouts consisted of bilateral leg presses, short-arc extensions, lunges, step-ups, eyes-closed unilateral squats, Fitter (Fitter International, Inc, Calgary, AB, Canada) or slide, tubing, and lazy-S running. On even days, the workouts consisted of squats, leg extensions and curls (including isokinetics), walking lunges, step-ups, and lazy-circle running. In addition she was biking, stair climbing, and jogging for cardiorespiratory conditioning.

EVALUATION AND TESTING

On the first visit, we performed a complete evaluation and assessment, including computerized eccentric contraction break tests (J-Tech Power Tracker, Heber City, UT) bilaterally to identify any strength imbalances (Figure 1). We found no point tenderness or lack of range of motion but did find 1 cm of joint effusion when compared bilaterally at the joint lines. The Lachman and anterior drawer sign revealed moderate visible joint laxity. A modified Thomas test was performed bilaterally to evaluate hip mobility (Figure 2). This test is performed by having the athlete sit on the edge of a table; with the support of the athletic trainer or physical therapist, the athlete lies back with both knees drawn up to the chest. One knee is held to the chest (locking out the pelvis and lumbar

Table 2. Complementary Home Exercise Program

Exercise	Sets	Repetitions or Time
Single-leg jump rope	3	30 s, increase to 1.5 min
Single-leg squats	3	15 repetitions
Resisted scissored running	3	15 s
Resisted heel slide (lower leg internally rotated)	3	15 repetitions

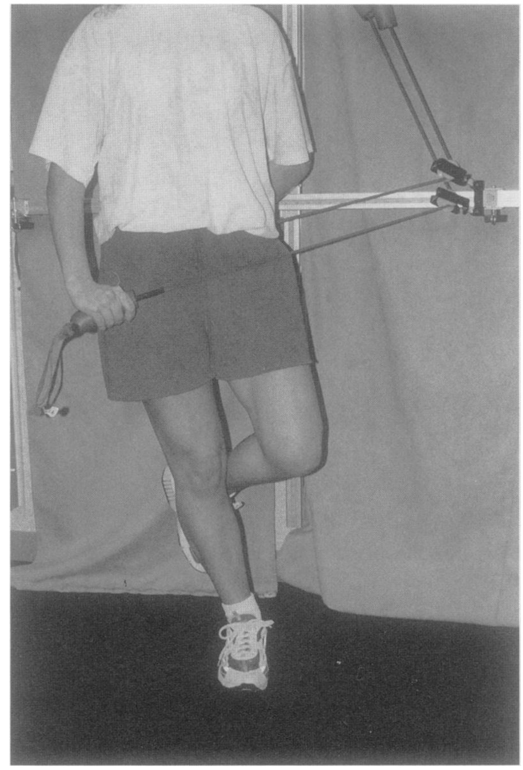

Figure 3. Athlete performing OTIS.

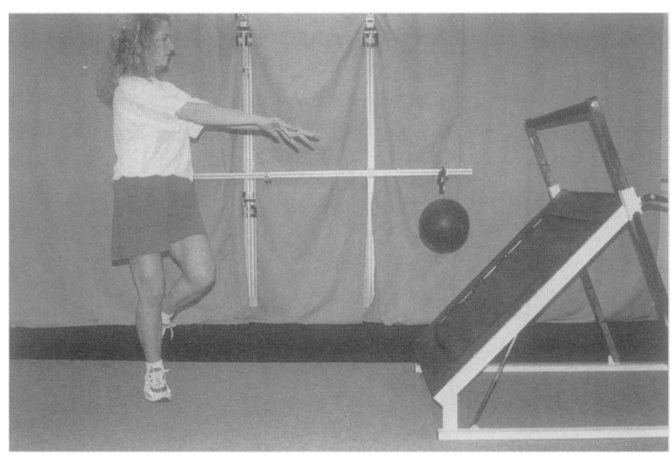

Figure 4. Athlete performing ITIS.

spine), and the other leg is relaxed off the table edge. If the knee range of motion is less than 90°, the rectus femoris muscle is tight; if the thigh remains elevated (<0° hip extension) above the table, then the iliopsoas muscle is tight. If the thigh and lower leg fall or turn out laterally (external rotation of the tibia or abduction of the femur), the iliotibial band may be tight.[1,12] As confirmed by a computer manual muscle test, this athlete was found to have a tight iliotibial band on the involved side, which is usually indicative of adductor weakness.

Functional testing was performed by means of resisted medial-lateral weight-shift running. The ability to load and unload the extremities was compared bilaterally. This test was done in order to simulate change-of-direction movements on the court without having to actually perform the movement on a gymnasium floor. Foot contacts were counted over a 15-second period and compared medially and laterally. Closed chain kinesthetic awareness was assessed through a timed, unilateral stance with eyes open and then with eyes closed. Isometric endurance was assessed by a timed, unilateral 90-degree isometric wall squat. A single-leg hop test was used to test strength and power; the distance jumped by each leg was measured.

These functional tests revealed no significant deficits between the involved and the uninvolved sides. We used 10% as the cutoff point for a significant difference between the extremities. This percentage is commonly used, because it allows for unilateral limb dominance.[13,14] The fact that functional tests revealed no significant deficits with bilateral comparison was interesting, considering the results of the computer dynamometer test (Table 1). This test confirms the body's ability, by sacrificing quality movements in order to perform effectively, to make muscular compensations. If we had not analyzed the individual components through the computerized dynamometry, we would have overlooked some of the areas that could have been serving as weak links and could have led to microtraumatic changes over time.

The computer dynamometer test involved hip medial and lateral rotation, hip abduction and adduction, hip flexion and extension, and knee flexion (laterally rotated) and extension. These movements were tested by performing an eccentric break test on the muscle or muscle group. Many muscles in the lower extremity contract eccentrically to help stabilize the knee and hip. The purpose of this type of muscle testing is to isolate these muscles eccentrically, while also providing a comparison between the strength of the muscles surrounding the knee and those surrounding the hip. If the hip movements had not been tested, major weaknesses and muscular imbalances that can increase stress on the knee might have been overlooked. The athlete might have returned to competition with significant hip weaknesses.

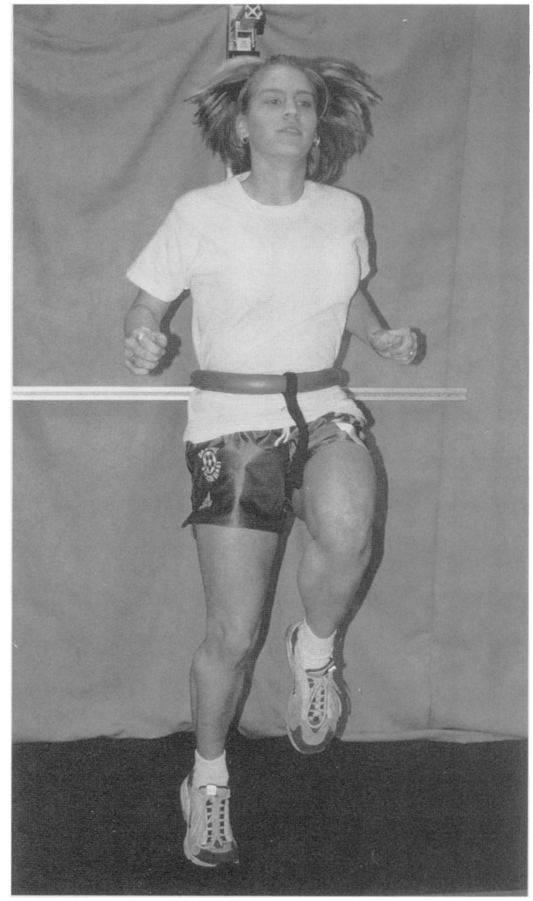

Figure 6. Athlete performing resistive running with a posterior weight shift (XTS, CDM Sports, Fort Worth, TX).

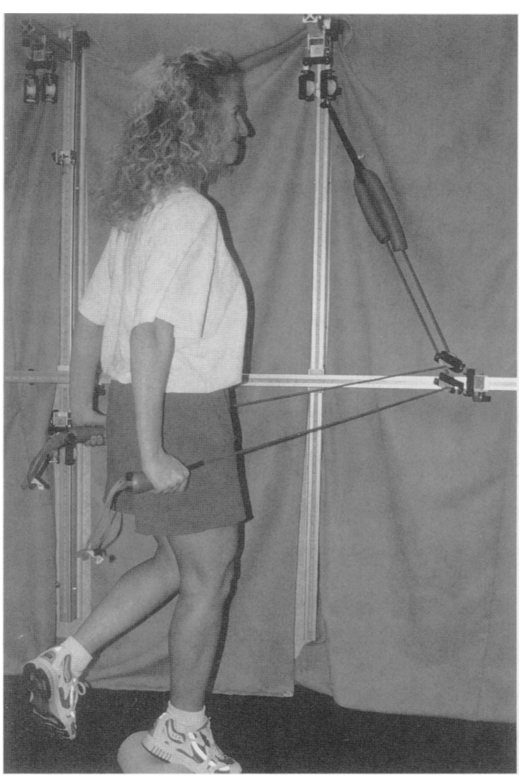

Figure 5. Athlete performing OTIS in plantar-flexed position.

The computer dynamometer results revealed significant weakness (>10%) when compared bilaterally in hip medial rotation, hip adduction, and knee flexion (laterally rotated) and knee extension (Table 1). Thus, there was a strength imbalance with regard to medial and lateral stability. (The other muscles tested revealed no significant weaknesses.)

REHABILITATION AND TRAINING

Our main focus was to resolve the noted deficits about the involved extremity, while improving knee joint stability, since full mobility had already been obtained. The athlete had also been training mostly in an anterior-posterior plane using isokinetics. Our goal was to now advance her training, gearing it toward multiplanar and functional activities, while continu-

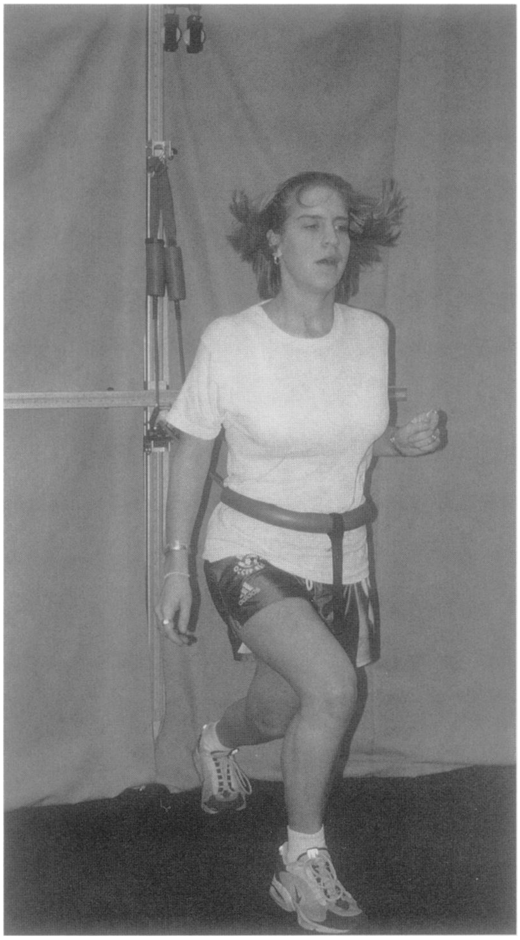

Figure 7. Athlete performing resistive scissored running with a posterior weight shift.

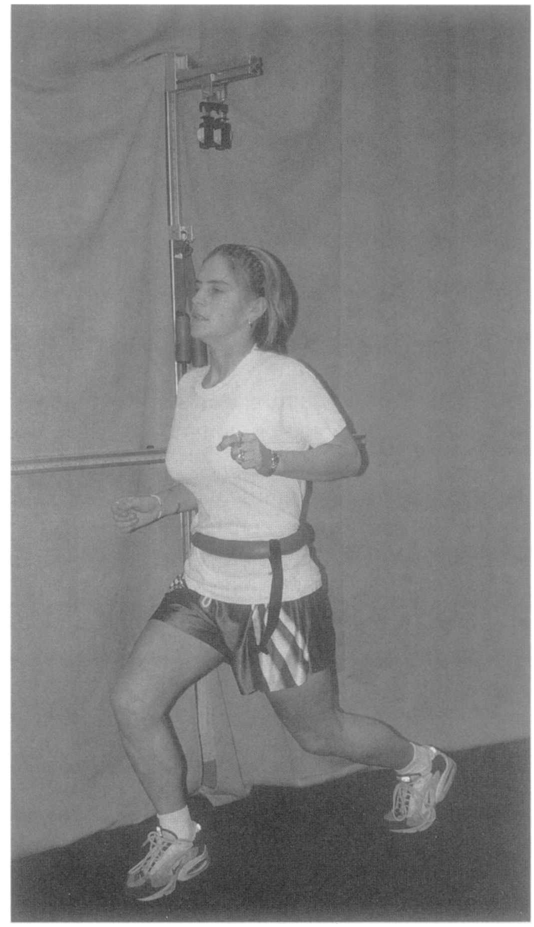

Figure 8. Athlete performing resistive scissored running with a lateral weight shift.

ing to focus on the deficits at hand. We sought to accomplish this through a progression of RNT. It was imperative that our exercises be specific enough to address the imbalances at hand, yet effective during the limited time allotted. We decided that an interval program would accommodate both the athlete's functional needs and her conditioning concerns. In addition to the clinic program, a complementary home exercise program was established (Table 2).

Our first task was to promote isometric stabilization for static control and posture with the goal of advancing to dynamic stabilization. This was done to decrease the body's need to compensate for quality movements. Two types of stability techniques, described by Voight and Cook,[5] were chosen to stimulate mechanoreceptor and muscle spindle function in a closed chain situation. The first technique, oscillating technique for isometric stabilization (OTIS), incorporates short, rapid oscillatory movements of an uninvolved body part to promote isometric stabilization of the involved body part. This technique is accomplished by having the arms pull elastic tubing fixed to the wall (Figure 3). This is helpful because the involved leg does not initiate any movement, but has only to react to weight shifting generated by arm movements, thus emphasizing the proprioceptive role of the lower extremity.

A complementary technique, impulse technique for isometric stabilization (ITIS), was performed with a plyoback training aid. ITIS provides for quick and repetitive loading and unloading or impulses within a short arc of movement (Figure 4). The same principle could be applied by throwing a medicine ball with a partner. The correct posture and positioning are imperative so that the involved mechanoreceptors are appropriately stimulated for joint proprioception.

OTIS and ITIS techniques may be applied in different directions to elicit involvement from various muscle groups. For our athlete, based on the imbalances found on the tests, we felt that directional emphasis would accommodate strengthening of the hip medial rotators, hip adductors, tibial medial rotators, and knee extendors. The applicable directions for the OTIS and ITIS techniques place the involved extremity away from the wall or rebounder with the foot at a 45-degree angle. The athlete must overcome rotational forces in this position while focusing on the muscle weaknesses in order to maintain proper posture and position. A foam roll added under the heel further increased musculature involvement in

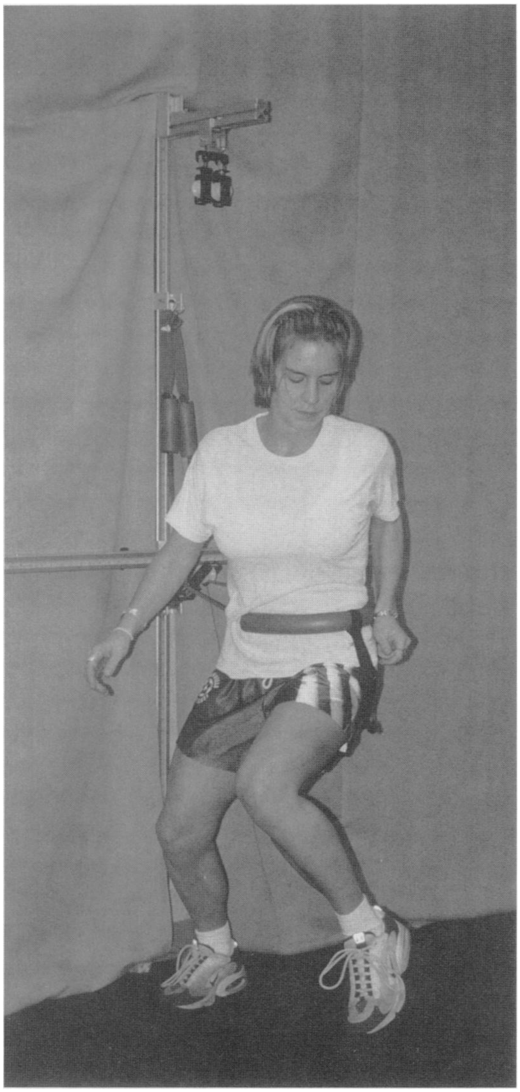

Figure 9. Athlete performing resisted bounding with a lateral weight shift.

order to maintain ankle, knee, and hip stability during the exercise (Figure 5).

We then implemented exercises that were progressively dynamic in nature to strengthen the hip and knee musculature while maintaining the athlete's cardiorespiratory endurance. She was able to immediately begin resistance activities, such as running, bounding, and scissored running, due to the performance scores established on the functional tests. She performed these activities with medial-lateral resistance and anterior-posterior resistance (Figures 6-9). These types of resistance focused on hip medial rotation, hip adduction, knee flexion, and knee extension. We, however, focused more on medial resistance activities in order to emphasize hip medial rotation and adduction, due to the computer dynamometry results.

The third aspect of her training incorporated progressive plyometrics. These movements use the neuromuscular stretch reflex and require greater degrees of dynamic stability than the

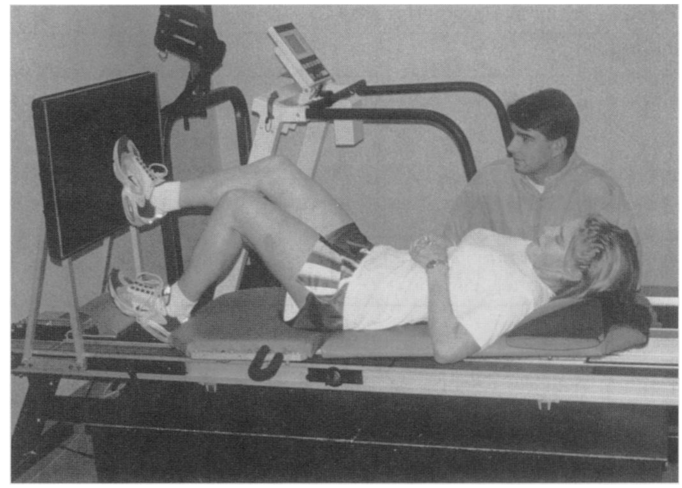

Figure 10. Athlete performing plyotaps on Shuttle 2000 (Contemporary Design Co, Glacier, WA).

previously mentioned activities. Activities within this phase also simulate the forces encountered during sport participation. They include plyometric demands, kinesthetic forces, and energy systems demands. The athlete performed plyotaps, or jumping with a graded resistance (Figure 10). This exercise emphasizes eccentric loading and vertical plyometrics. The athlete's day-to-day training regimen is outlined in Tables 3–6 (Figures 11 and 12).

The fifth visit included the same activities as the fourth visit. The last visit was scheduled solely to retest and review an ongoing home exercise program.

Upon completion of our brief rehabilitation, the manual computer dynamometer muscle tests were repeated. No functional tests were performed because there were no functional deficits during the pretest. The dynamometry posttest revealed some astonishing results: hip medial rotation on the involved side went from being 40% deficient to only 13% deficient, and the knee extension, knee flexion laterally rotated, and hip adduction deficits had resolved (Table 7).

DISCUSSION

We know from past research that improvements in true strength may take several weeks to occur; however, there is some evidence to support substantial gains in what appears to be strength by our subject. These gains often occur within the first 6 weeks with various forms of weight training. The reason for these changes is most often attributed to neuromuscular changes, including better coordination and im-

Table 3. Training Regime for Day 1

Exercise	Sets	Repetitions or Time
1) Walking: warm-up to 2.46 m/s jog on treadmill	1	5 min
2) Flexibility routine on BackSystem3	1	10 repetitions each
3) Review of home program		

Table 4. Training Regime for Day 2

Exercise	Sets	Repetitions or Time
1) Walking: warm-up to 2.46 m/s jog (interval jog between activities)	1	5 min
2) Flexibility routine on BackSystem3	1	10 repetitions each
3) ITIS unilateral in plantar flexion	3 (4 directions)	30 repetitions
4) OTIS unilateral in plantar flexion	3 (4 directions)	30 repetitions
5) Resisted running	3 (4 directions)	15 s
6) Leg press bilaterally, 8 cords	3	20 repetitions
7) Plyotaps (eccentric loading) bilaterally, 8 cords	3	20 repetitions
8) Cool-down after 2.46 m/s jog	1	5 min

Table 5. Training Regime for Day 3

Exercise	Sets	Repetitions or Time
1) Walking warm-up to 2.46 m/s jog (interval jog between each activity)	1	5 min
2) Flexibility routine on BackSystem3	1	10 repetitions each
3) ITIS unilateral in plantar flexion	3 (4 directions)	30 repetitions
4) OTIS unilateral in plantar flexion	3 (4 directions)	30 repetitions
5) Resisted bounding	3 (4 directions)	15 s
6) Plyotaps (eccentric loading) bilaterally, 8 cords	3	20 repetitions
7) Unilateral wall squats, 90° knee flexion	3	20 repetitions
8) Cool-down after 2.46 m/s jog	1	5 min

Table 6. Training Regime for Day 4

Exercise	Sets	Repetitions or Time
1) Walking warm-up to 2.46 m/s jog (interval jog between each activity)	1	5 min
2) Flexibility routine on BackSystem3	1	10 repetitions each
3) ITIS unilateral in plantar flexion	3 (4 directions)	30 repetitions
4) OTIS unilateral in plantar flexion	3 (4 directions)	30 repetitions
5) Resisted scissored running	3 (4 directions)	15 s
6) Plyotaps (eccentric loading) bilaterally, 8 cords	3	20 repetitions
7) Unilateral wall squats, 90° knee flexion	3	20 s
8) Cool-down after 2.46 m/s jog	1	5 min

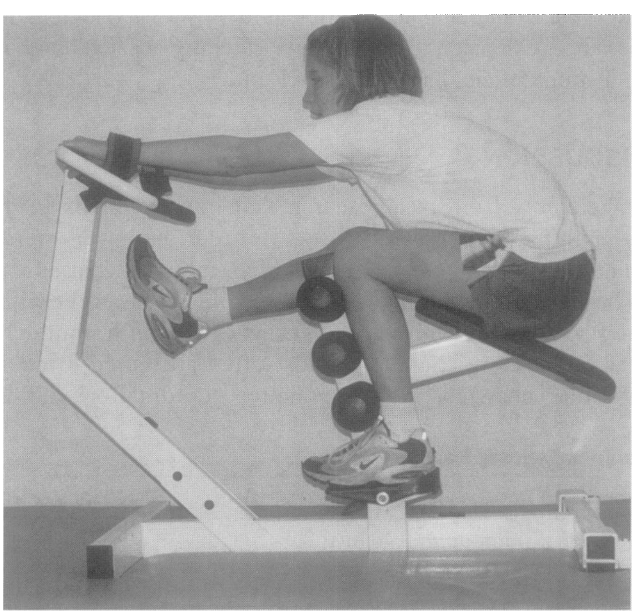

Figure 11. Athlete performing stretching routine on BackSystem3 (BackSystem3, CDM Medical, Fort Worth, TX).

proved recruitment. The human body has the inherent ability to recognize and react to movements that it identifies as familiar or patterned, which may be stored in muscle memory. The stability exercises that we chose for rehabilitation use similar movement patterns and allow the body to react appropriately with little compensatory activity. By implementing appropriate purpose, posture, positioning, and patterning, we can more efficiently affect the athlete's state of functioning. Since we treated the athlete only over an 8-day period, her progress and testing results would seem to

Table 7. Computer Dynamometer Test Comparing Right and Left Lower Extremities, December 27 (Refer to Table 1)

	Left (kg)	Right (kg)	Deficit (%)
Hip medial rotation	12.70	10.89	−13 R*
Hip adduction	26.31	25.85	−3 R
Knee flexion (lateral rotation)	21.32	21.32	0
Knee extension	31.75	29.03	−9 R

* R, right leg (the involved side).

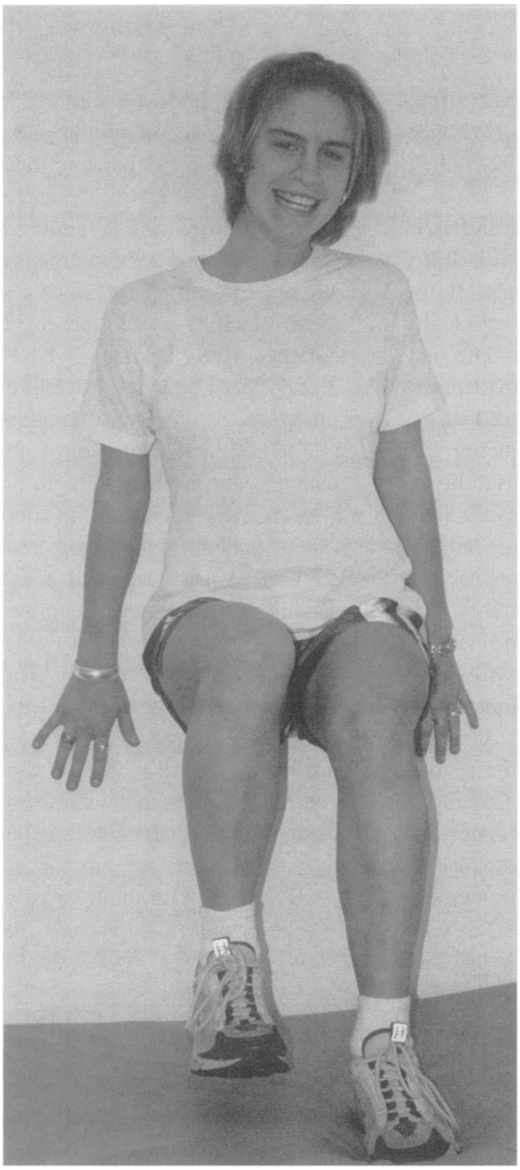

Figure 12. Athlete performing unilateral wall squats.

indicate neuromuscular adaptations and not just improved strength.

The athlete already had a well-established rehabilitation program, focusing on uniplanar movements, such as flexion-extension isokinetics and leg presses. Our focus was on multiplanar movements, focusing on the hip musculature imbalances. We felt that by shifting our focus to more medial-lateral and rotational-type activities, we could place the athlete in a more functional position while addressing the noted deficits.

The ability to identify the hip muscular imbalances and then use a more multiplanar and sport-specific training model provided the athlete with a more solid foundation for postseason competition. If these imbalances had not been identified, she would have continued to sacrifice knee stability to compensate for hip muscular imbalances. This might have led to more knee and hip problems and a longer rehabilitation after surgery.

The athlete did return to competition and completed a successful season. She continued to train throughout the remainder of the season using her home exercise program. At the end of the season, she underwent reconstruction and was then rehabilitated by her collegiate athletic trainer. The athlete had an excellent recovery after surgery with a continuation of her previous rehabilitation protocol. We believe that the RNT techniques applied before surgery helped to eliminate some of the primary imbalances that could have have led to a more complicated and less active recovery. Also, the athlete's diligent work ethic should be given credit in collaboration with our training program. She did everything we asked of her and was extremely compliant with her independent home program.

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