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Neuromuscular Strengthening Exercises Following ACL And Meniscal Repair In A 15 Year Old Female Athlete With Generalized Knee Laxity: A Case Report

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The patient's parent/guardian signed an informed consent allowing the use of the patient's medical information and video footage for this report and received information on the institution's policies regarding the Health Insurance Portability and Accountability Act.

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ABSTRACT

Background and Purpose

Adolescent females are 4-6 times more likely to sustain a non-contact anterior cruciate ligament (ACL) injury compared to their male counterparts.[1] Generalized knee laxity decreases dynamic knee stability and further increases injury risk.[2] In patients with a history of bilateral knee hyperextension who have sustained an ACL injury, it's vital to recover function after surgery, as well as prevent injury in the contralateral knee. A lack of information exists that addresses simultaneous rehabilitation protocols. The purpose of this case report was to investigate the use of a neuromuscular strengthening program in both the ACL injured and un-injured knees in an adolescent female with generalized knee laxity.

Case Description

The patient was a 15-year-old female athlete who sustained an ACL and medial meniscus tear in her left knee competing in the long jump for the first time. Initial deficits were found in strength, range of motion, balance, and gait due to surgery. She reported a history of bilateral knee hyperextension. Progressive neuromuscular exercises included squats, single-leg step downs, and dynamic balance using cues for visual, proprioceptive, and postural feedback.

Outcomes

Left quadriceps strength progressed from 2-/5 to 4/5 after 9 weeks of therapy. Flexion ROM improved from 100° to 120° and extension was attained. The patient's Lower Extremity Functional Scale scores improved from 26/80 to 54/80. Hyperextension improvements included ability to control the right knee during all exercises and while walking and running.

Discussion

A neuromuscular strengthening protocol that focused on neutralizing hyperextension influences was beneficial in an adolescent female patient post ACL reconstruction. Future studies should investigate the best practices to address underlying generalized knee laxity in adolescent females with ACL injuries.

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BACKGROUND and PURPOSE

Anterior cruciate ligament (ACL) injury rates are increasing among athletes participating in high-level sports. A population becoming increasingly more affected is adolescent females, who are 4-6 times more likely to rupture their ACLs compared to males their age. Reasons for this discrepancy have varied; however, adolescent females at risk have been shown to have poor neuromuscular control of lower limb biomechanics at the knee during pivoting, lateral movement, and landing tasks. A study by Hewett *et al* compared 3D biomechanical measures during jump-landing movement tasks of two groups of female athletes; those who had previously suffered an ACL injury and those who had not. The subjects with an ACL injury had a significantly altered neuromuscular control during the jump-landing, particularly with increases in dynamic lower extremity valgus and knee abduction loading compared to the non-injured subjects.[1] This can be attributed to deficits in proximal hip strength which directly contributes to knee abduction loading patterns and lower extremity valgus and is a significant predictor of future ACL injury risk.[2]

An additional risk factor increasing the susceptibility of female adolescents to ACL injury is increased ligamentous laxity. A study by Myer *et al* looked at the dynamic knee stability of female athletes and determined the prevalence of generalized knee joint laxity decreases stability and increases the odds of ACL injury status 5-fold.[3] It has also been reported that persons with

genu recurvatum have poor proprioceptive control at terminal degrees of knee extension, which leads to a reduced initiation of injury protection reflexes.[4]

Traditional rehabilitation following a surgical ACL reconstruction (ACLR) has focused on edema reduction, range of motion (ROM), strengthening, gait re-training, dynamic stability and neuromuscular exercises.[5] ACL injury prevention programs concentrated on neuromuscular control, proper biomechanical alignment, strength, agility and dynamic balance have prospectively been shown to decrease the incidence of ACL tears in female athletes.[6] Balancing rehabilitation protocols for a person with a surgically reconstructed ACL while also concentrating on injury prevention for generalized knee laxity of the contralateral knee can be challenging. It is crucial to return the surgically repaired knee to its former function. However, it is just as important to direct attention to the uninjured knee for improvements in neuromuscular control, biomechanical alignment, strength and kinesthetic awareness. Research has found that those who have torn one ACL are six time more likely to tear the contralateral ACL. [7] Therefore, it was hypothesized that a rehabilitation program addressing both the surgical and uninjured knees would improve functional outcomes and help prevent future injury.

Interventions highlighting both neuromuscular control and strength have been proven beneficial not only for prevention of ACL injuries in females, but also for regaining former function of the injured knee.[6,8] There is currently a lack of research directly addressing these components in a program for rehabilitation of the injured knee and prevention of the uninjured simultaneously. The purpose of this case report was to investigate the use of a progressive neuromuscular strengthening protocol in both the ACL injured and un-injured knees in an15 year old female athlete with generalized knee laxity post left ACLR and meniscal repair.

CASE DESCRIPTION

Patient History

The patient's mother signed an informed consent allowing the use of her medical information for this case report. The patient (JD) was a 15 year old adolescent female who sustained a left ACL and medial meniscal tear while performing the long jump for the first time in a track competition. This was JD's first year of indoor and outdoor track, previously only competing in hurdles and sprints. MRI and X-ray imaging confirmed the injury and she underwent surgery two weeks later. An ACL allograft reconstruction and medial meniscus repair were performed. Prior to injury, JD was an active member of the track team, played basketball, and participated in tae kwon do since she was a child. She lived in a supportive household with her parents and older sister. JD was in good health, with no poor health habits. She exercised regularly and had no co-morbidities that could affect her success with rehabilitation. She stated at the time of PT evaluation her pain level was a 1/10 and she was no longer taking narcotic medication, only Tylenol when needed. JD presented with no significant past medical or surgical history. She had a history of bilateral knee hyperextension. However, after surgical reconstruction of the left knee, it no longer extended as far as the right knee. The patient stated both her mother and sister have a history of knee hyperextension, but neither had sustained an injury in the past.

JD presented to physical therapy two weeks after surgery on axillary crutches with a 50% weight-bearing restriction. She was referred for therapeutic exercise to stretch and strengthen the left lower extremity (LE) through therapeutic modalities, progressive resistance exercise (PRE) and a home exercise program (HEP). The patient and family's main goals were to regain functional mobility and strength in order to return to her prior level of function and be able to participate in track at the start of indoor season in the fall.

Systems Review

A systems review was performed and the results are documented in Table 1. The musculoskeletal, neuromuscular, and integumentary systems were impaired. The patient had gross passive and active ROM limitations of the left knee. Pain was reported during passive extension. Muscular atrophy of the left quadriceps was noted. The patient had impaired balance and gait due to the use of crutches and limited weight-bearing. Post-surgical swelling and ecchymosis was noted surrounding the left knee and the incision sites appeared clean and dry.

Clinical Impression 1

Prior to therapy, the diagnosis was established and consistent with the injury, imaging, and surgical repair. She was approximately two weeks out of surgery at initial examination and was unable to bear full weight through the left LE due to precautions. Her presentation was as expected due to the nature of her injury and post-surgical protocols in place from the physician. All of these factors contributed to the patient's inability to achieve a normal gait pattern and functional mobility with her daily activities, as well as restricted her participation as a member of the track team.

Key features of the examination were to document deficits in ROM and strength of the left LE. Goniometric measures would be used to document ROM of the injured and uninjured knees. Functional strength of the left LE would be observed initially due to post-surgical precautions and protection of the healing process. Gross strength testing of the right LE would be performed to document that patient's baseline of LE strength. No special tests were performed due to surgery.

The patient was a good candidate for therapy because she was young, healthy, and highly motivated to return to her prior level of function. She was a good candidate for this case report because of her age, gender, and the correlation of ACL injuries and generalized knee laxity in

adolescent athletes. The development of physical therapy interventions focused on neuromuscular strengthening for rehabilitation and prevention of the injured and uninjured sides respectively.

Examination: Tests & Measures

Results of the initial examination, progress note, and final assessment can be found in Table 2. The patient's AROM of the left knee was impaired and limited to 100° of flexion and lacked 15° of extension. In addition, a measurement of her right knee hyperextension was documented at 10° representing the baseline measure of both knees prior to injury. Measurements were taken using a universal goniometer and performed as described by Norkin and White.[9] Measures of knee flexion and extension using goniometry was found reliable and valid by Gogia *et al*.[10] Manual muscle tests (MMT) were not performed on the left LE due to post-surgical precautions. Observation of left quadriceps strength was made upon attempted contraction and a functional straight-leg raise. The left quadriceps showed poor tone with the patient's attempt to elicit a single quadriceps set, but she was able to raise the entire extremity to approximately 45° without difficulty or pain. However, there was an extension lag of 5° indicating weakness of the quadriceps. MMTs were performed on the right LE, showing good strength throughout with 5-/5 for hamstrings and quadriceps and 4+/5 for the gluteal muscles. A literature review by Cuthbert and Goodheart analyzed more than 100 studies and found a large amount of evidence for the reliability and validity for the use of MMT.[11]

The left knee had residual post-surgical swelling and ecchymosis along the medial to lateral joint line, popliteal space and distal to the tibial tuberosity. Palpation confirmed the presence of edema surrounding the joint and tenderness near the tibial tuberosity. The incisions were healing well and covered with sterile bandages.

A Homan's sign is thought to be indicative of deep vein thrombosis (DVT) and is performed by dorsiflexing the patient's foot and/or the therapist applying pressure to the calf and assessing for pain. This test was found negative, however literature states this test can have little to no value when screening for DVT. [12]

JD reported experiencing very minimal pain, 1/10 on the 0-10 Numeric Rating Scale (NRS). According to Williamson and Hoggart, the NRS is both reliable and valid for use in clinical practice.[13] The patient's only complaint was her inability to functionally ambulate due to a 50% weight bearing restriction and the use of the crutches post-surgically. The weight bearing restrictions were consistent with the repair to the medial meniscus and were decreased through physician's orders.

The patient was given the Lower Extremity Functional Scale (LEFS) at the time of initial evaluation in order to track her perceived functional limitations with daily activity and movements. She scored a 26/80, indicating 68% impairment. This test is shown to be reliable, with sensitivity to change, and valid according to Binkley *et al.*[14] The LEFS was also used at the time of progress notes and discharge to document progress.

Clinical Impression 2

Based on the examination information, the initial impression was consistent with a post-surgical ACL and meniscus repair. The patient's limited strength, ROM, and functional ambulation were features of post-surgical presentation and improved with further healing and interventions. The next step was to proceed with physical therapy highlighting neuromuscular strengthening for restoration of function to the left knee, as well as prevention of future injury to the right knee. The patient followed up with her surgeon at regularly scheduled intervals for weight-bearing and exercise progression in accordance with graft healing.

The patient continued to be appropriate for this case because of her current limitations and strength and stability deficits found in the examination. She was a good candidate to receive intervention procedures due to the nature of the injury, corresponding history of bilateral knee hyperextension, and athletic background. That patient's short and long-term goals are summarized in Table 3.

The physical therapy diagnosis for this patient is 4I: Impaired Joint Mobility, Motor Function, Muscle Performance, and Range of Motion Associated With Bony or Soft Tissue Surgery. The patient's prognosis with physical therapy was good given her age, health, and motivation to return to her prior level of function. Her compliance with her home exercise program and active participation in therapy contributed to her prognosis for improvement. However, it is important to maintain the appropriate strength and re-train kinesthetic awareness of the uninjured knee. Without the appropriate care, female athletes are 6 times more likely than male athletes to suffer a contralateral ACL injury when returning to sports without adequate strength and neuromuscular control.[7]

INTERVENTIONS

Coordination, Communication, and Documentation

A plan of care (POC) was established after initial examination and evaluation were performed. Coordination with the orthopedic surgeon was essential for progression of weight bearing and ROM restrictions, as well as, ensuring proper healing of the graft sites. For a consistent treatment plan, it was imperative the lines of communication between all therapists remain open regarding current interventions being provided. Clear and concise documentation was performed with electronic medical records in order to fax the surgeon updates and to allow for other therapists to track changes and note improvements.

Patient / Client Related Instruction

The patient and family were initially educated on the importance of maintaining weight bearing status to allow for proper healing of the ACL graft and medial meniscus repair. Additionally, she was educated on the approximated timeline of her recovery, from attaining full weight bearing for walking to when she would return to running. Risk factors were discussed including the possibility of future injury to the right knee due to her history of hyperextension, upon returning to high loading activities. A HEP was given to the patient at initial examination to address the decreased muscle performance of the left quadriceps, as well as the lack of terminal knee extension. The exercises to target these two areas were single quadriceps sets, straight-leg raises, and a heel prop for terminal knee extension. Descriptions of these exercises are located in Appendix 1, along with the modifications and advancements made per the ACL rehabilitation protocol as the patient progressed. The initial HEP was instructed to be performed 2 times a day for the first two weeks of PT.

Procedural Interventions

The timeframe of this case report was nine weeks in length. The patient continued to receive care at this clinic for another three weeks before she was discharged at 12 weeks. The patient attended therapy during this time twice a week and the sessions were one hour in length.

The procedural interventions for this patient focused on using a progressive neuromuscular control and strengthening protocol in both the ACL injured and uninjured knees. Initially during the first 4 weeks of post-surgical rehabilitation, the major focus of intervention was on achieving terminal knee extension and restoring muscle activation of the left quadriceps. The patient's compliance with the HEP was important at this stage because of how these limitations can effect ambulation and her future functional mobility if not attained.

For the purpose of this case report, the following interventions were performed between phases 2 and 3 of the rehabilitation protocol (5-10 weeks post-surgically) and are additionally described in Table 4. It was at this point in the rehabilitative process the patient made successful ROM gains and was safely able to perform PRE while incorporating balance and proprioception into dynamic movement. In order to target and strengthen the involved extremity, while also implementing appropriate sagittal plane movement patterns, closed chain exercises for the left quadriceps muscle were initiated. At 5 weeks, the patient started on a 4" platform and performed a single leg step down by keeping the left foot on the platform, bending the left knee, and slowly lowering the right heel to the ground. A strong emphasis was placed on the slow eccentric contraction of the quadriceps as the right leg was lowered. The patient then returned to the starting position by contracting the left quadriceps to extend the knee. Verbal and tactile feedback was provided by the therapist in order to maintain proper knee kinetics and alignment. This exercise unmasked the weakness of the patient's hip abductors as she exhibited a dynamic knee valgus and ipsilateral hip drop with the first attempt. Decreased functional hip strength and diminished core proprioception have been shown to alter dynamic frontal plane knee motion during landing and is a predictor of ACL injury risk.[2, 15] In addition, core and hip stabilization and strength allows for the control of deceleration during landing activities, as well as preventing LE valgus with dynamic tasks.[16] The home exercise program was then expanded to include gluteus medius raises and clamshells with TheraBand™** for increased pelvic stability. The single leg step down was performed for 10 repetitions initially and progressed up to 15 repetitions over the course of the following 3 weeks. The progression of the exercise included adding height to make it a 6" platform (Figure 1), and using an AirEx®ǂ foam pad underneath the left foot to challenge the balance of the entire left LE (Figure 2).

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As the patient continued to show progress, dynamic exercises were introduced during the 6th and 7th week to challenge strength and stability bilaterally. At this point in the patient's treatment, implementation of neuromuscular strengthening exercises for injury prevention on the right side was deemed appropriate. These exercises included double legged squats, walking lunges, BOSU®* step ups, and single leg balance activities. These activities allowed for an increased challenge to quadriceps strength, specifically the VMO, in a dynamic environment that tasked balance and proprioception. During the 8th week, these exercises were advanced by having the patient hold a weighted ball to implement core and trunk stability and strengthening. Feedback was given to the patient during all interventions regarding the avoidance of hyperextension in the right knee, with use of the mirror, verbal and tactile cues. This was emphasized to encourage the patient to attain awareness of her right knee mechanics to reduce hyperextension and match the surgically repaired left knee.

The patient was cleared by her physician to begin jogging during the 9th week of therapy. Initially, the patient was instructed to perform light jogging outside on a level surface. The patient began to work on midfoot strike for avoiding heel contact and related hyperextension on the right side. The patient was able to progress to treadmill running for variable cadence and increased endurance.

Throughout the course of treatment, the physical therapist made changes to the interventions to increase the strength of the lower extremities, challenge balance and proprioception, and engage core and postural stability. It was imperative that interventions were designed to regain the patient's functional mobility, strength, coordination, and neuromuscular control of bilateral lower extremities in order to safely return her to the high demand loading involved with track. Neuromuscular training techniques were emphasized and advanced in order to focus on bilateral

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LE dynamic stabilization and to reduce the strength deficit between the right and left quadriceps. It has been shown that significant reduction in quadriceps strength of the involved limb increases movement asymmetries during landing, alters kinetic patterns of the knee and ultimately places higher loading rates on the uninjured limb.[17] Therefore it was vital to ensure there was no increased risk of injury to the right knee, especially due to her history of hyperextension.

Outcomes

Measurements from the patient's final assessment were taken at nine weeks and described in Table 2. ROM on the surgically repaired left knee improved from 100 to 120 degrees for flexion and from 15 to 0 degrees for extension. Left quadriceps strength progressed from 2-/5 to 4/5 after nine weeks of therapy. The right quadriceps and hamstrings made strength gains from 5-/5 to 5/5, noting improvement but also highlighting the current strength asymmetry between sides. Hyperextension improvements included the ability to control the right knee during all exercises and while walking and jogging. Finally LEFS scores improved from 26/80 to 54/80. The patient met all goals upon discharge at 12 weeks and transitioned to a gym program in preparation for the upcoming track season.

Discussion

A great deal of research has been conducted around programs targeted to reduce ACL injury risk. The Prevent Injury and Enhance Performance (PEP) program was designed by Mandelbaum *et al* to use neuromuscular and proprioceptive sports-specific training to reduce the risk of ACL injury in uninjured, youth female soccer players. Implementation of the PEP program was able to reduce ACL injury by 74% in a two year-follow up study.[17] Additional research has shown that interventions highlighting both neuromuscular control and strength have proven beneficial not

only for prevention of ACL injury in females, but also for regaining former function of the injured knee.[6,8]

A neuromuscular strengthening protocol focused on restoring function of the injured knee, while promoting prevention of the uninjured knee, was beneficial for this 15 year old post ACL and meniscus repair. This case report showed observational results similar to the studies mentioned above for the decreased risk of contralateral ACL injury due to the patient's increased awareness of body mechanics to combat knee hyperextension during dynamic tasks. Emphasis should be placed on a return to sport program for all adolescent females' post ACLR for further PRE and neuromuscular training to decrease the strength discrepancy between the right and left quadriceps.

Future studies should investigate the best practices in addressing the underlying generalized knee laxity, in addition to, neuromuscular centered programs for rehabilitation of the injured knee and prevention of the uninjured knee simultaneously. Findings such as these would be beneficial for providing the most effective rehabilitation in adolescent females who have sustained an ACL injury and for reducing contralateral risk factors through prevention, education, and awareness.

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Tables & Figures

Table 1: Systems Review Results from Initial Examination

System	System Status
Musculoskeletal	Left LE: AROM: Impaired/Limited Flexion & Extension Gross Strength: Impaired Right LE: Not impaired
Neuromuscular	Gait / Locomotion: Impaired
Integumentary	Impaired: Incision site medial to patellar tendon clean, dry and covered with steri-strips. Multiple small incisions on lateral and medial aspect of left knee clean and dry. Residual post-surgical swelling and ecchymosis surrounding left knee
Cardiovascular/Pulmonary	There were no significant findings for cardiovascular or pulmonary systems.
Communication Affect, Cognition, Learning Style	Patient was alert and oriented x3 and preferred demonstration and pictures for the home exercise program.

Abbreviations: LE, lower extremity; AROM, active range of motion; x3, person place and time

Table 2: Test and Measures & Outcome Measurements Made from Initial Examination to Final Assessment

Tests & Measures	Impairments at Initial Examination (S/P 2 weeks)	Impairments at Progress Report (S/P 7 weeks)	Impairments at Final Assessment (S/P 11 weeks)
Range of Motion	L LE: Flexion: 100° Extension: (15°) R LE: Hyperextension 10°	Flexion: 120° Extension: 0° R LE: Hyperextension 10°	Flexion: 120° Extension: 0° R LE: Hyperextension 10°
Manual Muscle Testing B/L LE Strength	**L LE**: not formally tested (noted poor quadriceps tone with attempted contraction & extension lag with functional SLR) **R LE:** Quads: 5-/5 Hamstrings: 5-/5 Gluteus Maximus: 4+/5 Glute Medius: 4+/5	**L LE:** Quads: 3+/5 Hamstrings: 4/5 Gluteus Maximus: 4/5 Gluteus Medius: 4/5 **R LE:** Quads: 5-/5 Hamstrings: 5-/5 Gluteus Maximus: 4+/5 Gluteus Medius: 4+/5	**L LE:** Quads: 4/5 Hamstrings: 4+/5 Gluteus Maximus: 4+/5 Gluteus Medius: 4+/5 **R LE:** Quads: 5/5 Hamstrings: 5/5 Gluteus Maximus: 4+/5 Gluteus Medius: 4+/5
Numeric Pain Rating Scale (0-10)	Best: 0 Worst: 3 Current: 1 Description: Dull/Achy	Best: 0 Worst: 0 Current: 0	Best: 0 Worst: 0 Current: 0
Gait / Locomotion	-50% WB per physician protocol -Antalgic -Using axillary crutches	-FWB (as of 6/22) -Antalgic -Decreased terminal knee extension at heel strike	-Normal gait pattern -Decreased stride length of left leg compared to right -Return to jogging
Palpation	Popliteal space – edematous Tibial tuberosity – painful to light palpation Medial / Lateral joint line – edematous	Normal tenderness and decreased inflammation of popliteal space and medial/lateral joint line	Normal tenderness and decreased inflammation of popliteal space and medial/lateral joint line
Outcome Measure: Lower Extremity Functional Scale	Score: 26/80	Score: 45/80	Score: 54/80

Abbreviations: S/P, post-surgical; SLR, straight leg raise; B/L, bilateral; LE, lower extremity; WB, weight bearing; FWB, full weight bearing

Table 3: Short and Long-Term Goals

Short-term Goals	Long-term Goals
The patient will achieve active left knee flexion of 110° in order to allow for functional tasks such as ascending stairs and ambulation by 4 weeks.	The patient will achieve active left knee flexion of 120° in order to allow for functional tasks such as descending stairs by 6 weeks.
The patient will increase ambulation to full weight bearing without the use of assistive device, per physician, by 5 weeks in order to more easily access her home and school environment.	The patient will gain full terminal knee extension for normal gait pattern and functional ambulation by 6 weeks.
The patient will increase terminal knee extension to (5°) to influence proper heel strike and decrease antalgic gait pattern by 5 weeks.	The patient will increase left quadriceps strength to 4+/5 by 8 weeks in order to improve functional mobility.
The patient will increase left quadriceps strength to 4-/5 in order to improve functional mobility and promote terminal knee extension by 5 weeks.	The patient will achieve functional strength of entire left lower extremity to within normal limits by 16 weeks in order to return to prior level of function and activities.

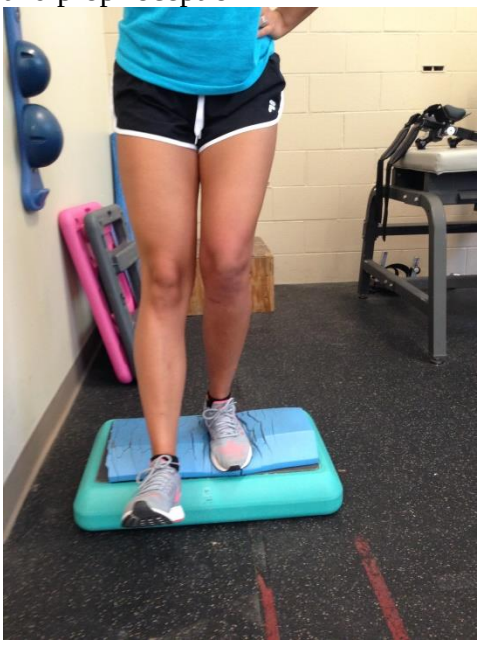
Table 4: Progression of Neuromuscular Strengthening Interventions based on Physical Therapy Phases of Post-Surgical ACL Repair Protocol (Appendix 1)

Post-op PT Phase	Interventions Provided	Clinical Reasoning	Modifications Made
Phase 2 (2-6 weeks)	NMES for quadriceps activation	Increasing patient's ability to contract quadriceps on her own	-Discontinued at 10 weeks post-op
	Stretching for TKE	Regain extension ROM for heel strike	-Progressed to TKE against resistance (TBand)
	Straight leg raise	Continue strengthening of quadriceps	-Addition of 2-5lb ankle weight
	Hip PREs: Ext/Abd	Improvement of hip and pelvic stability	-Addition of ankle weights / multi-hip machine
	Single leg step up / down	Improving quadriceps strength concentrically and eccentrically, feedback for proper knee kinematics	-Step up: Increasing level from 4"-6" -Step down: Beginning at 4"-6"
	Leg press	Increase B/L leg strength, SL strength, and VMO activation	-Addition of 35# -DBL to SL -Adductor ball squeeze
	Gait training	Return gait pattern to normal	-Increase to FWB, normalize stride length
	Recumbent bike	Increase flexion ROM	Progress resistance and time to increase endurance
Phase 3 (6-10 weeks)	Single leg balance	Increase left knee balance and proprioception statically and dynamically	-Performed on AirEx -Static with arm movement & medicine ball -SL balance and trampoline ball throw
	Lunges	Increase LE strengthening and knee kinematics	-Static with left leg forward -Dynamically alternating legs
	DBL squat	Reinforce proper landing mechanics	-Addition of medicine ball for core stability -Performed on AirEx to challenge stability
Phase 4 (10-16 weeks)	Single leg step down	Incorporate balance and proprioception into strengthening	Performed on AirEx
	Begin jogging	Practice normalizing jogging gait	Performed outside on a level surface, progressed to treadmill

Abbreviations: NMES: neuromuscular electrical stimulation; PREs: progressive resistance exercises; Ext: extension; Abd: abduction; DBL: double leg; SL: single leg; B/L: bilateral; VMO: vastus medialis oblique; TKE: terminal knee extension; FWB: full weight bearing; LE: lower extremity; ROM: range of motion; Tband: TheraBand®

Figure 1: Patient performing single leg step down on 6” platform for eccentric quadriceps strengthening and control

Figure 2: Progression of single leg step down exercise on AirEx foam pad for increased balance and proprioception



Appendix 1

ACL Rehabilitation Protocol Provided from Attending Orthopedic Surgeon

Phase 2: Physical Therapy Rehabilitation (2-6 weeks)

- Introduce home exercise program (**focus for first 2 weeks**)
  - **Single quadriceps set**: place small towel underneath the extended left knee and to contract the quadriceps and hold for 10 seconds (10 reps, 2 sets, 2x/day)
  - **Straight leg raises**: contract the quadriceps and raise the entire left leg to 45° and hold for 10 seconds (10 reps, 2 sets, 2x/day)
  - **Heel prop for terminal knee extension**: place the heel onto a table or supportive surface while sitting down with the left knee extended forward. This position was designed to allow gravity to assist in stretching the knee into extension and was held anywhere from 5-10 minutes, per patient's tolerance.
- Gait training with crutches (D/C crutches between 2 and 4 weeks)
- Modalities to reduce swelling, pain and increase muscle activity (NMES, ultrasound)
- ROM goals 0-120 degrees (must gain full extension in this phase)
- Short arc quadriceps (SAQ) and straight leg raise exercises in supine
- Heel slides progressing to stationary bicycle
- Wall slides and mini squats
- Multi-hip progressive resistance exercises (PRE's) in all directions
- Step ups/downs 2" platform and progress to 6" as tolerated
- Leg press
- Calf raises / stretches
- Proprioception training: single leg balance, stork stands, biomechanical ankle platform system (BAPS)
- SAQ in standing

Phase 3: Physical Therapy Rehabilitation (6-10 weeks)

- Lunges and lateral step-ups
- BOSU step-ups
- Straight line jogging may begin on treadmill and progress to turf
- Advance PREs on all machines as tolerated
- Agility drills
- High speed isokinetic exercises

Phase 4: Sport Specific and plyometric exercises (10-16 weeks)

- Low speed isokinetics
- Jump rope
- Forward hops
- Cycling
- Advance running drills, figures 8s, run cut left, back peddling
- Specific sport related technical and skill drills