

ANTERIOR CRUCIATE LIGAMENT (ACL) RECONSTRUCTION: HAMSTRING AUTOGRAFT

Background

The following anterior cruciate ligament (ACL) reconstruction rehabilitation protocol is specific to patients with a hamstring autograft. If a patellar tendon or quadriceps tendon autograft was used, please refer to the “Anterior Crucial Ligament (ACL) Reconstruction: Patellar Tendon Autograft” or “Anterior Crucial Ligament (ACL) Reconstruction: Quadriceps Tendon Autograft” protocol on the OSU Sports Medicine website.

The rehabilitation recommendations below are based upon the guidance of content experts, evidence-based practice and the Multicenter Orthopaedic Outcomes Network (MOON) group. Progression through each phase is based on the patient demonstrating readiness by achieving functional criteria rather than the time elapsed from surgery. The times frames identified after each phase are approximate times for the average patient, NOT guidelines for progression.

Disclaimer

Progression is time and criterion-based, dependent on soft tissue healing, patient demographics and clinician evaluation. If you are working with an Ohio State Sports Medicine patient and questions arise, please call 614-293-2385.



Summary of Recommendations

Precautions	<ol style="list-style-type: none"> 1. No testing of repaired or reconstructed ligaments (Lachman, Anterior/Posterior Drawer, Varus/Valgus Stress) prior to 12 WEEKS 2. No isotonic resisted hamstring exercises for 8 WEEKS with hamstring autograft 3. Meniscus Repair: <i>Always refer to operative note or reach out to surgical team for clarification (general precautions below)</i> <ol style="list-style-type: none"> a. No weight-bearing (WB) therapeutic exercise >90° x 8 WEEKS b. No forced flexion beyond 90° x4 WEEKS
Outcome Tools	<p>Collect the Lower Extremity Functional Scale (LEFS) at each visit</p> <p>Consider collecting one of the following outcome tools at initial evaluation, monthly and discharge. Be consistent with which outcome tool is collected each time.</p> <ol style="list-style-type: none"> 1. IKDC 2. KOOS <p>You may choose to include ACL-RSI, Tegner or other questionnaires specific to your patient's needs.</p>
Strength Testing	<ol style="list-style-type: none"> 1. Isometric testing fixed at 90° - anytime 2. Isokinetic testing no earlier than 12 weeks
Criteria to Discharge Assistive Device	<ol style="list-style-type: none"> 1. <u>ROM</u>: Full active knee extension; no pain on passive overpressure 2. <u>Strength</u>: Able to perform strong quad isometric with full tetany and superior patellar glide and able to perform 2x10 SLR without quad lag 3. <u>Effusion</u>: 1+ or less is preferred (2+ acceptable if all other criteria are met) 4. <u>Weight Bearing</u>: Demonstrates pain-free ambulation without visible gait deviation
Criteria to Initiate Running	<ol style="list-style-type: none"> 1. <u>ROM</u>: full, pain-free knee ROM, symmetrical with the uninvolved limb 2. <u>Strength</u>: Isokinetic testing 80% or greater for hamstring and quad at 60°/sec and 300°/sec 3. <u>Effusion</u>: 1+ or less 4. <u>Weight Bearing</u>: normalized gait and jogging mechanics 5. <u>Neuromuscular Control</u>: Pain-free hopping in place
Criteria for Return to Sport	<ol style="list-style-type: none"> 1. <u>ROM</u>: full, painfree knee ROM, symmetrical with the uninvolved limb 2. <u>Strength</u>: Isokinetic testing 90% or greater for hamstring and quad at 60°/sec and 300°/sec 3. <u>Effusion</u>: No reactive effusion ≥ 1+ with sport-specific activity 4. <u>Weight Bearing</u>: normalized gait and jogging mechanics 5. <u>Neuromuscular control</u>: appropriate mechanics and force attenuation strategies with high level agility, plyometrics, and high impact movements 6. <u>Functional Hop Testing</u>: LSI 90% or greater for all tests 7. <u>Physician Clearance</u>



RED/YELLOW FLAGS

Red flags are signs/symptoms that require immediate referral for re-evaluation. Yellow flags are signs/symptoms that require modification to plan of care.

<p>Red Flags</p> <p>Require immediate referral for re-evaluation</p>	<ul style="list-style-type: none"> • Signs of DVT → Refer directly to ED <ul style="list-style-type: none"> ○ Localized tenderness along the distribution of deep venous system ○ Entire LE swelling ○ Calf swelling >3cm compared to asymptomatic limb ○ Pitting edema ○ Collateral superficial veins • Lack of full knee extension by 4 weeks post-op → Refer to surgeon for re-evaluation • Mechanical block or clunk → Refer to surgeon for re-evaluation • Reported episode of instability → Refer to surgeon for re-evaluation
<p>Yellow Flags</p> <p>Require modifications to plan of care</p>	<ul style="list-style-type: none"> • Persistent reactive effusion or pain following therapy or ADLs <ul style="list-style-type: none"> ○ Decrease intensity of rehab interventions, continue effusion management, educate patient regarding activity modifications until symptoms resolve

Pre-Operative Phase (Initial Injury - Surgery)

<p>Appointments</p>	<ul style="list-style-type: none"> • If we have the opportunity to work with patients prior to surgery, be cautious with visit use pre-operatively to optimize post-operative care • Emphasize home program and patient education, with occasional check-ins to monitor progress and update program
<p>Goals</p>	<ol style="list-style-type: none"> 1. Full active (AROM) and passive (PROM) knee extension 2. Knee flexion ROM to a minimum of 120° 3. Trace to zero effusion via Sweep Test (Appendix C) 4. No extension lag with SLR 5. Ideally: Quadriceps LSI ≥ 80% of uninvolved limb (handheld dynamometry, isometric, isokinetic) <ul style="list-style-type: none"> • Retain these values for post-operative comparison to minimize overestimation of strength
<p>Patient Education</p>	<ul style="list-style-type: none"> • Importance of pre-operative PT to optimize post-operative outcomes → especially regarding ROM and post-operative stiffness • Home program instruction between surgery and first post-operative appointment • Anticipated RTS timeline (9-12+ months) • DVT signs/symptoms for acute post-operative phase
<p>Suggested Interventions</p>	<ul style="list-style-type: none"> • Extension: bag hangs (Appendix A), prone hangs, heel prop towel stretch → Goal: 60 min total /day • Flexion: heel slides, wall slides → Goal: 300+ repetitions/day • Quad isometric • Prone TKE • SLR – flexion, abduction • Double leg squat – emphasis on equal loading • Gait correction



Protection Phase (Post-ACLR – 4 weeks)

Appointments	<ul style="list-style-type: none"> • Goal: Restore ROM, minimize effusion and pain. • Post-operative evaluation should be performed 3-5 days following surgery. • Follow-up appointments 1-2x per week, depending on progression towards goals.
Precautions	<ol style="list-style-type: none"> 1. No testing of repaired or reconstructed ligaments (Lachman, Anterior/Posterior Drawer, Varus/Valgus Stress) prior to 12 WEEKS 2. Meniscus Repair: <i>Always refer to operative note or reach out to surgical team for clarification (general precautions below)</i> <ol style="list-style-type: none"> a. No weight-bearing (WB) therapeutic exercise >90° x 8 WEEKS b. No forced flexion beyond 90° x4 WEEKS
Pain and Effusion	≥ 2+ (using Modified Stroke Test) – Appendix C Cryotherapy and compression (ie. Donut, ace wrap, limited WB therapeutic exercise)
ROM	<p><u>Extension:</u> Emphasis on achieving full knee extension immediately following surgery. Utilize low load, long duration stretching – See Appendix A.</p> <ul style="list-style-type: none"> • If full extension is not achieved by 4 weeks, contact surgeon regarding ROM concerns. <p><u>Flexion:</u> No forced flexion past 90° for meniscus repairs. ACLR and meniscectomy can push for symmetrical flexion as appropriate.</p>
Therapeutic Exercise	<ul style="list-style-type: none"> • Emphasis on quad activation without gluteal co-contraction • Restore patellar mobility • Symmetrical ROM • Decrease effusion • Ambulation with appropriate joint loading and without obvious gait deviation
Open Chain Knee Extension Progression	<p>Open Chain knee extension:</p> <ul style="list-style-type: none"> • Unresisted LAQ – week 1 (partial → full range) • Multi-angle isometrics at 90° and 60°– weeks 2-3 • LAQ with cuff weight – week 2-3 • Partial range knee extension machine (90° - 45°) – week 3
Suggested Interventions	<ul style="list-style-type: none"> • Extension ROM: bag hangs or prone hangs (<i>Appendix A</i>) • Flexion ROM: heel slides, wall slides, upright bike • Patellar mobilization: superior, inferior, medial, lateral • Quad Isometrics; SLR 4-way • TKE: prone and standing • OKC extension as outlined above • Weight shifting, SL balance • Gait correction • Neuromuscular re-education using electrical stimulation (NMES) at 60° knee flexion
Blood Flow Restriction Training <i>Appendix D</i>	<ul style="list-style-type: none"> • Blood Flow Restriction (BFR) training can be initiated as soon as sutures are removed • Ensure patient has no contraindications (Appendix D) and if patient has any listed precautions or are at risk for a DVT, clear with physician before initiating BFR • Use BFR twice weekly for up to 10 weeks; use for 2-3 exercises per session • Can be used with any exercise that is safe for patient to perform depending on time since surgery (ex. SLR 4-way, prone TKE). <i>BFR should never be performed during a plyometric exercise.</i> • Training Load: 20-40% 1 RM (Estimated, or use OMNI-RES, see Appendix D) • Limb Occlusion Pressure= 80% (see Appendix D if patient unable to tolerate) • 4 sets for each exercise with reps of 30-15-15-15 (75 total) with a 30 second rest break between sets, keeping cuff inflated the entire duration of each exercise. Deflate between exercises, or every 8 minutes.



**NMES
Parameters**
Appendix B

- NMES pads are placed on the proximal and distal quadriceps
- Patient: Seated with the knee in at least 60° flexion, shank secured with strap and back support with thigh strap preferred. The ankle pad/belt should be two finger widths superior to the lateral malleoli
- The patient is instructed to relax while the e-stim generates at least 50% of their max volitional contraction against a fixed resistance OR maximal tolerable amperage without knee joint pain
- 10-20 seconds on/ 50 seconds off x 15 min

**Criteria to
Discharge
Assistive
Device**

1. ROM: Full active knee extension; no pain on passive overpressure
2. Strength: Able to perform strong quad isometric with full tetany and superior patellar glide and able to perform 2x10 SLR without quad lag
3. Effusion: 1+ or less is preferred (2+ acceptable if all other criteria are met)
4. Weight Bearing: Demonstrates pain-free ambulation without visible gait deviation

**Criteria to
Progress to
Early Loading
Phase**

ROM: ≥ 0-120 degrees
Strength: Quadriceps set with normal superior patellar translation, SLR x 10 seconds without extensor lag
Goals: (These do not limit progression to next phase; however, should be addressed with interventions)
Effusion: 2+ or less with Modified stroke test (Appendix C)
Weight Bearing: Able to tolerate CKC therex program without increased pain and ≤ 2+ effusion



Early Loading Phase (4-8 weeks)

Appointments	Goal: to improve LE loading symmetry, increase strength and normalize gait mechanics. 1-2 visits per week with emphasis on HEP compliance (2-3 days per week outside of therapy).
Precautions	Avoid isotonic resisted hamstring exercises for 8 WEEKS with hamstring autograft
Pain and Effusion	Cryotherapy/compression as needed for reactive effusion. Patellar taping to reduce PF symptoms if present
ROM	<ul style="list-style-type: none"> • Monitor and progress knee ROM, patellar mobility, and LE flexibility • Continue bike for ROM and warm up • If full AROM knee extension is not achieved by 4 weeks, contact surgeon regarding ROM concerns.
Open Chain Knee Extension Progression	Open Chain knee extension: <ul style="list-style-type: none"> • Progress multi-angle isometric to include 90°, 60° and 30° – week 4 • Knee extension machine (full range) – week 4 <ul style="list-style-type: none"> ○ Monitor for anterior knee pain and modify as appropriate ○ Progress via resistance, speed/type of contraction
Suggested Interventions and timelines	<ul style="list-style-type: none"> • OKC as described • Progress WB quadriceps exercises with emphasis on proper LE mechanics (no isolated HS strengthening until 8 weeks) • Progress gluteal and lumbopelvic strength and stability • Progress single leg balance • Endurance: low impact - treadmill walking, stepper, elliptical (6 weeks; 10 minutes minimum) • BFR (continue as in early phase, adding appropriate exercises) • Continue NMES
Criteria to d/c NMES	<ul style="list-style-type: none"> • <20% quadriceps deficit on isometric testing <p>OR- If a Biodex machine is not available:</p> <ol style="list-style-type: none"> 1. 10 SLR without quad lag 2. Normal gait 3. 10 heel taps to 60 degrees with good quality 4. 10 rep max on LP and similar effort bilaterally <ul style="list-style-type: none"> • Inability to break quad MMT
Criteria to Progress to Strength and Power Phase	<ol style="list-style-type: none"> 1. <u>ROM</u>: Maintain full, pain free AROM including PF mobility 2. <u>Effusion</u>: 1+ or less 3. <u>Strength</u>: See criteria to discharge NMES 4. <u>Weight Bearing</u>: Able to tolerate therapeutic exercise program without increased pain or >1+ effusion 5. <u>Neuromuscular Control</u>: Demonstrates proper lower extremity mechanics with all therapeutic exercises (bilaterally)



Strength and Power Phase (8-12 weeks)

Appointments	Goal to increase lower extremity strength and power. 1-2 visits per week with emphasis on patient compliance with resistance training as part of HEP (2-3 days per week outside of therapy).
Pain and Effusion	Cryotherapy/compression as needed for reactive effusion. Patellar taping to reduce PF symptoms if present
ROM	<ul style="list-style-type: none"> • Monitor and progress knee ROM, patellar mobility, and LE flexibility <ul style="list-style-type: none"> ○ Continue end-range ROM interventions as needed ○ Contact surgical team regarding ROM concerns • Consider higher level warm ups including bike sprints or versaclimber
Suggested Interventions and timelines	<ul style="list-style-type: none"> • Continue quadriceps loading as described in previous phase • BFR (continue as in early phase, adding appropriate exercises) • Initiate isolated hamstring interventions at 8 weeks <ul style="list-style-type: none"> ○ RDL ○ Physioball hamstring curl ○ Hamstring curl machine • Progress gluteal and lumbopelvic strength and stability • Progress single leg balance • Continue NMES
Criteria to initiate Running and Jumping	<ol style="list-style-type: none"> 1. <u>ROM</u>: full, pain-free knee ROM, symmetrical with the uninvolved limb 2. <u>Strength</u>: Isokinetic testing 80% or greater for hamstring and quad at 60°/sec and 300°/sec (Appendix E and F) 3. <u>Effusion</u>: 1+ or less 4. <u>Weight Bearing</u>: normalized gait and jogging mechanics 5. <u>Neuromuscular Control</u>: Pain-free hopping in place (DL and SL hops in place)
Criteria to Progress to Return to Function Phase	<ol style="list-style-type: none"> 1. <u>ROM</u>: Maintain full, pain free AROM including PF mobility 2. <u>Effusion</u>: 1+ or less 3. <u>Strength</u>: Isometric or isokinetic quadriceps and hamstrings strength \geq 80% 4. <u>Weight Bearing</u>: Able to tolerate therapeutic exercise program, including jogging progression, without increased pain or $>1+$ effusion 5. <u>Neuromuscular Control</u>: Demonstrates proper lower extremity mechanics with all therapeutic exercises (bilaterally) 6. <u>Outcome Tools</u>: \geq7/10 on #10 IKDC Questionnaire



Return to Function Phase (12 weeks-Return to Sport)

Appointments	Increased frequency from previous stage to initiate plyometric training and return to running program.
Precautions	<p>Criteria to initiate hopping</p> <ul style="list-style-type: none"> • Full, pain free ROM • ≤ 1+ effusion • ≥ 7 /10 on #10 IKDC Questionnaire • ≥ 80% isokinetic strength symmetry (hamstrings and quadriceps) OR ≥ 80% limb symmetry on acceptable isokinetic alternative Appendix E and F <p>Criteria to initiate jogging (in addition to above criteria)</p> <ul style="list-style-type: none"> • Hop downs with appropriate landing mechanics <ul style="list-style-type: none"> ◦ DL (starting at 6-8" and progressing per patient's tolerance) → SL (starting at 2-4" and progress per patient's tolerance) • Audible rhythmic strike patterns and no gross visual compensation
Pain and Effusion	Effusion may increase with increased activity, ≤1+ and/or non-reactive effusion for progression of plyometrics
ROM	Full, symmetrical to contralateral limb, and painfree with overpressure
Therapeutic Exercise	<ul style="list-style-type: none"> • Performance of the quadriceps, hamstrings and trunk dynamic stability • Muscle power generation and absorption via plyometrics • Sport- and position-specific activities • Begin agility exercises between 50-75% effort (utilize visual feedback to improve mechanics as needed) • Advance plyometrics: Bilateral to single leg, progress by altering surfaces, adding ball toss, 3D rotations, etc.
Suggested Interventions	<p>Therapeutic Exercise/Neuromuscular Re-education</p> <ul style="list-style-type: none"> • Squats, leg extension, leg curl, leg press, deadlifts, lunges (multi-direction), crunches, rotational trunk exercises on static and dynamic surfaces, monster walks, PWB to FWB jumping • Single-leg squats on BOSU with manual perturbation to trunk or legs, Single-leg BOSU balance, single-leg BOSU Romanian deadlift <p>Agility</p> <ul style="list-style-type: none"> • Side shuffling, Carioca, Figure 8, Zig-zags, Resisted jogging (Sports Cord) in straight planes, backpedaling <p>Plyometrics</p> <ul style="list-style-type: none"> • Single-leg hop downs from increasing height (up to 12" box), Single-leg hop-holds, Double and single-leg hopping onto unstable surface, Double and single-leg jump-turns, Repeated tuck jumps
Criteria for Return to Sport	<ol style="list-style-type: none"> 1. <u>ROM</u>: full, pain free knee ROM, symmetrical with the uninvolved limb 2. <u>Strength</u>: Isokinetic testing 90% or greater for hamstring and quad at 60°/sec and 300°/sec 3. <u>Effusion</u>: No reactive effusion ≥ 1+ with sport-specific activity 4. <u>Weight Bearing</u>: normalized gait and jogging mechanics 5. <u>Neuromuscular control</u>: appropriate mechanics and force attenuation strategies with high level agility, plyometrics, and high impact movements 6. <u>Functional Hop Testing</u>: LSI 90% or greater for all tests 7. <u>Physician Clearance</u>



Appendix A: Bag Hang

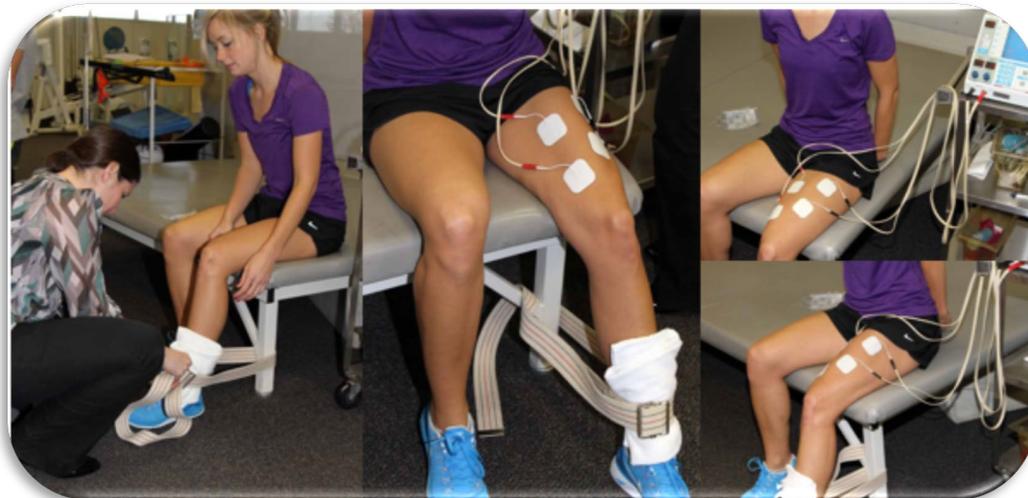
Emphasis on low load, long duration stretching.

Goal: 60 minutes TOTAL per day (4x15 minutes, 2x30minutes, etc)



Appendix B: NMES Set Up

2 or 4 pad set-up is appropriate



THE OHIO STATE UNIVERSITY
WEXNER MEDICAL CENTER

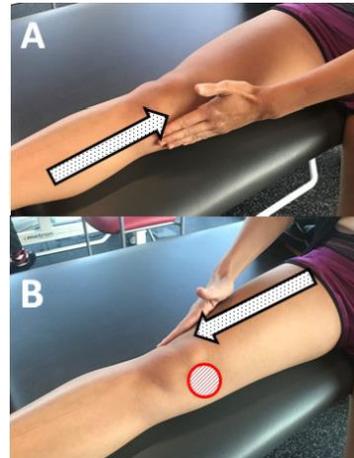
For OSUWMC USE ONLY. To license, please contact the OSU Technology Commercialization Office at <https://tco.osu.edu>.

Appendix C: Stoke Test / Swelling Assessment

The Stroke Test

The stroke test is a great way to assess your swelling independently. The results of this assessment will help you decide what exercises are appropriate.

- A. Using one hand, gently sweep the inside portion of your knee 2-3 times (pushing toward the hip joint).
- B. On the outside portion of the knee, immediately sweep downward (toward the ankle). Watch the inside portion of the knee (*indicated by hashed circle in photo*) for a wave of fluid to appear during the downstroke.



Grading System

(Table adapted from Sturgill L et al, Journal of Orthopaedic & Sports Physical Therapy, 2009)

Test Result	Grade
No wave produced on downstroke	Zero
Small wave on inside aspect of knee with downstroke	Trace
Large bulge on inside aspect of knee with downstroke	1+
Swelling spontaneously returns to inside aspect of knee after upstroke (no downstroke necessary)	2+
So much fluid that it is not possible to move the swelling out of the inside aspect of the knee	3+

Indications for Activity

3+ or 2+	1+	Trace or Zero
Red Light 	Yellow Light 	Green Light 
<ul style="list-style-type: none"> No running, jumping or cutting or heavy lifting until swelling decreases to 1+ or less Do not progress program until you speak with your therapist Utilize swelling management strategies (ice, compression, elevation, NSAIDs) 	<ul style="list-style-type: none"> Proceed with caution You may participate in running, jumping and normal lifting routine. Check effusion before and after workouts Utilize swelling management strategies (ice, compression, elevation, NSAIDs) 	<ul style="list-style-type: none"> May participate in running, jumping and normal lifting routine without restriction Continue to monitor swelling after activity



THE OHIO STATE UNIVERSITY

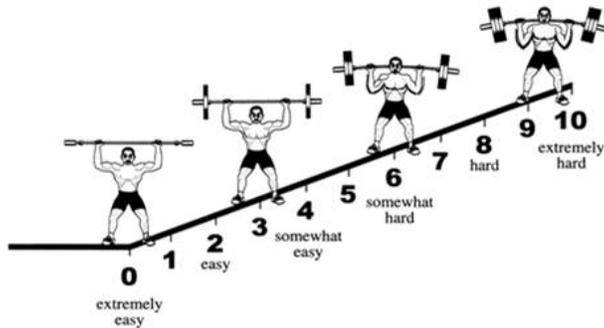
WEXNER MEDICAL CENTER

For OSUWMC USE ONLY. To license, please contact the OSU Technology Commercialization Office at <https://tco.osu.edu>.

Appendix D: Blood Flow Restriction Training

Precautions (must get permission from MD)	Contraindications
<ul style="list-style-type: none"> ▪ Patients with poor circulatory systems (Indicators: shining or scaly skin, brittle dry nails, extremity hair loss, increased capillary filling time, and presence of varicose veins) ▪ Patients who are obese or with limb tissue that is loose ▪ Arterial claudification ▪ Abnormal clotting times ▪ Diabetes ▪ Sickle cell trait ▪ Tumor ▪ General infection ▪ Hypertension ▪ Cardiopulmonary conditions ▪ Renal compromise ▪ Clinically significant acid-base imbalance ▪ Atherosclerotic vessels ▪ Taking anti-hypertensive medications 	<ul style="list-style-type: none"> ▪ Venous thromboembolism ▪ Impaired circulation or peripheral vascular compromise ▪ Previous revascularization of the extremity ▪ Extremities with dialysis access ▪ Acidosis ▪ Sickle cell anemia ▪ Extremity infection ▪ Tumor distal to the tourniquet ▪ Medications/supplements known to ↑ clotting risk ▪ Open fracture ▪ Increased intracranial pressure ▪ Open soft tissue injuries ▪ Post-traumatic hand reconstructions ▪ Severe crushing injuries ▪ Severe hypertension ▪ Elbow surgery with excessive swelling ▪ Skin grafts in which all bleeding points distinguished ▪ Secondary or delayed procedures after immobilization ▪ Vascular grafting lymphectomies ▪ Cancer

Training Intensity: 20-40% 1RM or use the Omnibus Resistance Exercise Scale (below). Patient chooses weight/resistance that corresponds to 2-3



Exercise Prescription:

- If Patient achieves:
 - 75 repetitions: continue with training, re-assess intensity within 1-3 sessions and change as strength improves
 - 60-74 repetitions: continue with training, but extend rest period between sets 3 and 4 to 45 seconds until 75 repetitions is completed
 - 45-59 repetitions: continue with training, but extend rest period between all sets to 45-60 seconds
 - <44 repetitions: reduce load by approximately 10% until repetitions are achieved
- If patient is forced to stop before 75 repetitions due to undue pain, soreness, or general uncomfortable feeling underneath the cuff → reduce tourniquet pressure by 10mmHg at each training session until cuff tolerance is achieved. Ramp cuff pressure back up by 10 mmHg to target limb occlusion pressure if patient can tolerate.



Appendix E: Isokinetic Data Interpretation



		Definition	Clinical Impact	What to do
A	Peak Torque (ft-lbs)	Peak torque during repetitions	Symmetry criteria (see 'E'- this is the data represented in pie charts)	If <80%; continue unilateral, high resistance strength training
B	Coefficient of Variance (%)	Between repetition variability	Goal: < 15%	If >15%, consider retest
C	Total Work (ft-lbs)	Torque over all repetitions	Possible indicator of fatigue	If >10%; consider high volume training
D	Agonist/Antagonist Ratio (%)	Hamstring/Quadriceps Ratio	Goal: >60%	<60%; ensure 1:1 quadriceps:hamstring exercise ratio
E	Limb Symmetry Pie Charts	Strength relative to involved limb	Goal: <10% asymmetry (either direction- deficit OR stronger on involved limb)	If <80%, continue NMES in addition to strength training If <90%, continue unilateral > bilateral strength training emphasis

Appendix F: Isokinetic Testing and Appropriate Alternatives

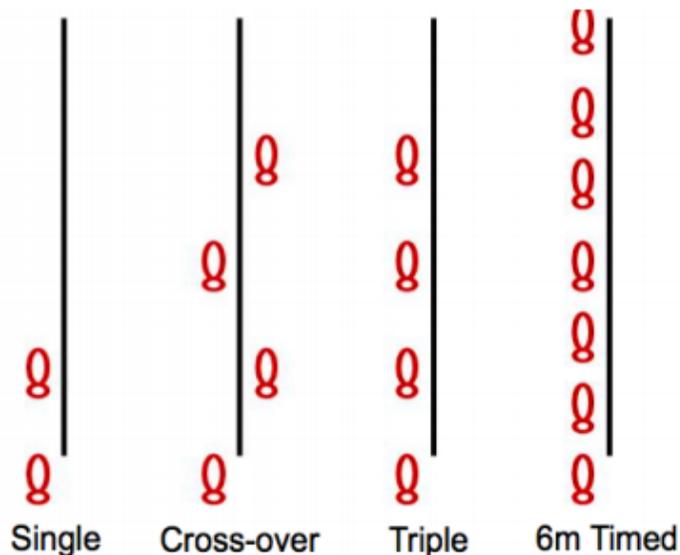
Sinacore, J. A., Evans, A. M., Lynch, B. N., Joreitz, R. E., Irrgang, J. J., & Lynch, A. D. (2017). Diagnostic accuracy of handheld dynamometry and 1-repetition-maximum tests for identifying meaningful quadriceps strength asymmetries. *Journal of orthopaedic & sports physical therapy*, 47(2), 97-107.

<p>Isokinetic Dynamometry</p>		<ul style="list-style-type: none"> • Considered the “gold standard” • 60°/sec for strength and power assessment • 300°/second for speed and endurance assessment
<p>Hand Held Dynamometry with Static Fixation at 90°</p>		<ul style="list-style-type: none"> • Appropriate alternative • Results may overestimate quadriceps strength symmetry: be cautious with data interpretation
<p>SL 1RM Knee Extension Machine: 90° - 45°</p>		<ul style="list-style-type: none"> • Appropriate alternative • Recommended to decrease stress on PF joint and limit strain on reconstructed ACL for up to 6 months • Results may overestimate quadriceps strength symmetry: be cautious with data interpretation
<p>SL 1RM Leg Press</p>		<ul style="list-style-type: none"> • Fair alternative • Results in significant overestimation of quadriceps strength symmetry due to compensation from other LE muscle groups
<p>SL 1RM Knee Extension Machine: 90° - 0°</p>		<ul style="list-style-type: none"> • Fair alternative • May be uncomfortable and/or inappropriate due to PF stress



Appendix G: Single Leg Hop Series

- 1) **Single hop for distance:** Have the subject line their heel up with the zero mark of the tape measure, wearing athletic shoes. The subject then hops as far as he/she can, landing on the same push off leg, for at least 3 seconds. The arms are allowed to move freely during the testing. Allow him/her to perform 2 practice hops on each leg. Then, have the subject perform 2 testing trial, recording each distance from the starting point to the back of the heel. Average the distanced hopped for each limb. The Limb Symmetry Index: Involved limb distance/Uninvolved limb distance X 100%.
- 2) **Cross-over hop for distance:** The subject lines their heel up with the zero mark of the tape measure and hops 3 times on one foot, crossing fully over the center line each time. Each subject should hop as far forward as he/she can on each hop, but only the total distance hopped is recorded. The arms are allowed to move freely during the testing. Allow him/her to perform 2 practice hops on each leg. Then, have the subject perform 2 testing trial, recording each distance from the starting point to the back of the heel. Average the distanced hopped for each limb. The Limb Symmetry Index: Involved limb distance/Uninvolved limb distance X 100%.
- 3) **Triple hop for distance:** The subject lines their heel up with the zero mark of the tape measure and hops 3 times on one foot. Each subject should hop as far forward as he/she can on each hop, but only the total distance hopped is recorded. The arms are allowed to move freely during the testing. Allow him/her to perform 2 practice hops on each leg. Then, have the subject perform 2 testing trial, recording each distance from the starting point to the back of the heel. Average the distanced hopped for each limb. The Limb Symmetry Index: Involved limb distance/Uninvolved limb distance X 100%.
- 4) **Timed 6-meter hop:** The subject lines their heel up at the zero mark of the tape measure and hops, on cue with the tester, as fast as they can the length of the 6-meter tape. The arms are allowed to move freely during the testing. Allow him/her to perform 2 practice hops on each leg. Then, have the subject perform 2 testing trial, recording each distance from the starting point to the back of the heel. Average the distanced hopped for each limb. The Limb Symmetry Index: Involved limb time/Uninvolved limb time X 100%.



Authors: Caroline Brunst, PT, DPT, SCS, AT and Kate Martin, PT, DPT, SCS

Reviewers: Evan Luse, PT, DPT; Stephanie Di Stasi, PT, PhD, OCS; Laura Schmitt, PT, PhD; Robert Magnussen, MD; David Flanigan, MD; Christopher Kaeding, MD

Updated: April 2023

References:

- Adams, D., Logerstedt, D., Hunter-Giordano, A., Axe, M. J., & Snyder-Mackler, L. (2012). Current Concepts for Anterior Cruciate Ligament Reconstruction: A Criterion-Based Rehabilitation Progression. *Journal of Orthopaedic & Sports Physical Therapy*, 42(7), 601–614. <https://doi.org/10.2519/jospt.2012.3871>
- Arundale, Amelia JH, et al. "Exercise-Based Knee and Anterior Cruciate Ligament Injury Prevention: Clinical Practice Guidelines Linked to the International Classification of Functioning, Disability and Health From the Academy of Orthopaedic Physical Therapy and the American Academy of Sports Physical Therapy." *Journal of Orthopaedic & Sports Physical Therapy* 53.1 (2023): CPG1-CPG34.
- Beischer S, Gustavsson L, Senorski EH, et al. Young athletes who return to sport before 9 months after anterior cruciate ligament reconstruction have a rate of new injury 7 times that of those who delay return. *J Orthop Sports Phys Ther*. 2020;50(2):83-90. doi:10.2519/jospt.2020.9071
- Capin JJ, Failla M, Zarzycki R, et al. Superior 2-Year Functional Outcomes Among Young Female Athletes After ACL Reconstruction in 10 Return-to-Sport Training Sessions: Comparison of ACL-SPORTS Randomized Controlled Trial With Delaware-Oslo and MOON Cohorts. *Orthop J Sport Med*. 2019;7(8):1-10. doi:10.1177/2325967119861311
- Capin JJ, Snyder-Mackler L, Risberg MA, Grindem H. Keep calm and carry on testing: A substantive reanalysis and critique of 'what is the evidence for and validity of return-to-sport testing after anterior cruciate ligament reconstruction surgery? A systematic review and meta-analysis'. *Br J Sports Med*. 2019;53(23):1444-1447. doi:10.1136/bjsports-2019-100906
- Diermeier T, Tisherman R, Hughes J, et al. Quadriceps tendon anterior cruciate ligament reconstruction. *Knee Surgery, Sport Traumatol Arthrosc*. 2020;28(8):2644-2656. doi:10.1007/s00167-020-05902-z
- Di Stasi, S., Myer, G. D., & Hewett, T. E. (2013). Neuromuscular Training to Target Deficits Associated With Second Anterior Cruciate Ligament Injury. *Journal of Orthopaedic & Sports Physical Therapy*, 43(11), 777-A11. <https://doi.org/10.2519/jospt.2013.4693>
- Escamilla RF, Macleod TD, Wilk KE, Paulos L, Andrews JR. ACL Strain and Tensile Forces for Weight Bearing and Non—Weight-Bearing Exercises After ACL Reconstruction: A Guide to Exercise Selection. *J Orthop Sport Phys Ther*. 2012;42(3):208-220. doi:10.2519/jospt.2012.3768
- Failla MJ, Arundale AJH, Logerstedt DS, Snyder-Mackler L. Controversies in knee rehabilitation: anterior cruciate ligament injury. *Clin Sports Med*. 2015;34(2):301-312. doi:10.1016/j.csm.2014.12.008
- Filbay SR, Grindem H. Evidence-based recommendations for the management of anterior cruciate ligament (ACL) rupture. *Best Pract Res Clin Rheumatol*. 2019;33(1):33-47. doi:10.1016/j.berh.2019.01.018
- Fleming BC, Oksendahl H, Beynnon BD. Open- or closed-kinetic chain exercises after anterior cruciate ligament reconstruction? *Exerc Sport Sci Rev*. 2005;33(3):134-140. doi:10.1097/00003677-200507000-00006
- Grindem H, Granan LP, Risberg MA, Engebretsen L, Snyder-Mackler L, Eitzen I. How does a combined preoperative and postoperative rehabilitation programme influence the outcome of ACL reconstruction 2 years after surgery? A comparison between patients in the Delaware-Oslo ACL Cohort and the Norwegian National Knee Ligament Registry. *Br J Sports Med*. 2015;49(6):385-389. doi:10.1136/bjsports-2014-093891
- Grindem H, Snyder-Mackler L, Moksnes H, Engebretsen L, Risberg MA. Simple decision rules can reduce reinjury risk by 84% after ACL reconstruction: the Delaware-Oslo ACL cohort study. *Br J Sports Med*. 2016;50(13):804-808. doi:10.1136/bjsports-2016-096031
- Myer, G. D., Chu, D. A., Brent, J. L., & Hewett, T. E. (2008). Trunk and Hip Control Neuromuscular Training for the Prevention of Knee Joint Injury. *Clinics in Sports Medicine*. <https://doi.org/10.1016/j.csm.2008.02.006>
- Noehren B, Snyder-Mackler L. Who's Afraid of the Big Bad Wolf? Open-Chain Exercises After Anterior Cruciate Ligament Reconstruction. *J Orthop Sports Phys Ther*. 2020;50(9):473-475. doi:10.2519/jospt.2020.0609
- Schmitt, L. C., Paterno, M. V., & Hewett, T. E. (2012). The Impact of Quadriceps Femoris Strength Asymmetry on Functional Performance at Return to Sport Following Anterior Cruciate Ligament Reconstruction. *Journal of Orthopaedic & Sports Physical Therapy*, 42(9), 750–759. <https://doi.org/10.2519/jospt.2012.4194>
- Shaarani SR, O'Hare C, Quinn A, Moyna N, Moran R, O'Byrne JM. Effect of prehabilitation on the outcome of anterior cruciate ligament reconstruction. *A J Sports Med*. 2013;41(9):2117-2127. doi:10.1177/0363546513493594
- Sinacore, J. A., Evans, A. M., Lynch, B. N., Joreitz, R. E., Irrgang, J. J., & Lynch, A. D. (2017). Diagnostic Accuracy of Handheld Dynamometry and 1-Repetition-Maximum Tests for Identifying Meaningful Quadriceps Strength Asymmetries. *Journal of Orthopaedic & Sports Physical Therapy*, 47(2), 97–107. <https://doi.org/10.2519/jospt.2017.6651>
- University of Delaware. "Rehabilitation after ACL Reconstruction: Practice Guidelines." April 2021
- Wright, R. W., Haas, A. K., Anderson, J., Calabrese, G., Cavanaugh, J., Hewett, T. E., ... Wolf, B. R. (2015). Anterior Cruciate Ligament Reconstruction Rehabilitation. *Sports Health: A Multidisciplinary Approach*, 7(3), 239–243. <https://doi.org/10.1177/1941738113517855>
- Yack HJ, Collins CE, Whieldon TJ. Comparison of closed and open kinetic chain exercise in the anterior cruciate ligament-deficient knee. *Am J Sports Med*. 1993;21(1):49-54. doi:10.1177/036354659302100109
- Zazulak, B. T., Hewett, T. E., Reeves, N. P., Goldberg, B., & Cholewicki, J. (2007a). Deficits in Neuromuscular Control of the Trunk Predict Knee Injury Risk. *The American Journal of Sports Medicine*, 35(7), 1123–1130. <https://doi.org/10.1177/0363546507301585>
- Zazulak, B. T., Hewett, T. E., Reeves, N. P., Goldberg, B., & Cholewicki, J. (2007b). The Effects of Core Proprioception on Knee Injury. *The American Journal of Sports Medicine*, 35(3), 368–373. <https://doi.org/10.1177/0363546506297909>

