Delaware Physical Therapy Clinic

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Rehabilitation after ACL Reconstruction: Practice Guidelines

Primary Surgery: ACL Reconstruction
Secondary Surgery (if applicable): Meniscal repair, meniscectomy, microfracture, chondroplasty, MCL injury, posterior lateral corner injury (appendix 1)
Expected # of visits: 20-46
Outcome Measures: KOS-ADLS, IKDC, ACL-RSI (short form) and Marx Activity Scale

Operational Definitions:
Phase Goals: Primary impairments targeted during a particular phase
Milestones: Minimum objective criteria required to progress to the next phase of rehab
Knee Joint Effusion Assessment: Sweep Test to assess intraarticular joint irritation (appendix 2)
Soreness Rules: To assess response to loading (appendix 3)
Full Knee Extension Range of Motion (ROM): Aim for symmetrical to uninvolved limb

Pre-Operative Rehabilitation
Phase Goals: Begin as soon as possible following initial injury to re-establish the following goals prior to surgery - Full active (AROM) and passive (PROM) knee extension - Knee flexion ROM within 10° of uninvolved limb - Trace to zero knee effusion - No knee extension lag with straight leg raise (SLR) - Quadriceps Strength Index (QI) ≥ 80% of uninvolved limb   ○ Retain values for post-operative comparison to minimize overestimation of strength

Patient Education:
- Importance of prehab for optimal post-operative outcomes
- What to do immediately after surgery (0-48 hours)
- Anticipated return to sport timeline: 9-12 months, allografts 12+ months
- Expected outcomes
  ○ Return to prior level of competition is often difficult, but possible
  ○ Osteoarthritis risk

<table>
<tr><th colspan="3">Immediate Post-Operative Phase (week 1)</th></tr>
<tr><td colspan="2">Phase Goals:
- At least 0° knee extension ROM
- Improve quad activation
- Decrease knee joint effusion
- Decrease pain
- Gait retraining on crutches</td><td>Milestones:
- ROM = 0-90°
- Active quad contraction with superior patellar glide
- Walking on crutches with superior patellar glide</td></tr>
<tr><th colspan="3">Treatment Strategies:</th></tr>
<tr><td rowspan="6">Total Visits:
1-2 visits

PT Frequency:
1-2x per week

HEP Frequency:
4-6x per day</td><td>ROM:</td><td>- Flexion 0-90°: wall slides, heels slides with strap, stationary bike

- Extension: heel prop, extension overpressure</td></tr>
<tr><td>Muscle Performance:</td><td>- Quad sets, long arc quad 90-0° (LAQ), standing and prone terminal knee extensions (TKEs), straight leg raise (SLR), ankle pumps

- Optional: low intensity Blood Flow Restriction (BFR) strength training for patients limited by pain or poor load tolerance</td></tr>
<tr><td>Manual Therapy:</td><td>- Patellar mobilization, flexion/extension PROM</td></tr>
<tr><td>Electric Stimulation:</td><td>- NMES dosed @ ≥ 50% of isometric MVIC (appendix 5)</td></tr>
<tr><td>Gait Training:</td><td>- WBAT on crutches with active quadriceps contraction</td></tr>
<tr><td>Modalities:</td><td>- Ice, elevation and compression (e.g. sleeve, compression wrap or donut wrap)</td></tr>
<tr><td colspan="3">Avoid unnecessary weight bearing throughout day to minimize effusion and pain. Elevate knee above heart level and ice as often as possible.

Criteria to discontinue use of brace/knee immobilizer (if used): SLR without lag, no increased pain or effusion with weight bearing and visible quad activation while ambulating in clinic. Crutches should be used as needed to normalize gait pattern and facilitate reduction in knee effusion.

Quadriceps MVIC Strength Testing: Isometric testing performed once able to assume test position (45-90° knee flexion) without pain. Utilize to appropriately dose NMES for quad strengthening each visit.

Home Exercise Program Recommendations:
Quad sets 5-10 sets of 100 x 5-10” per day, SLR (assisted as needed) 3 x 10, LAQ (90-0°) 30 x 5”, heel slides/seated assisted knee flexion/wall slides 30 x 5”, heel prop with ice 5 x 10 minutes per day, self-mobilization of patella 20 x 5” each direction</td></tr>
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<table>
<tr><th colspan="3">Early Post-Operative Phase (week 2-3)</th></tr>
<tr><td colspan="2">Phase Goals:
- Continue progressive impairment resolution
- Normalize gait
- SLR without a lag</td><td>Milestones:
- ROM = 0-115° (aim for hyperextension symmetrical to contralateral)
- Walking without crutches or immobilizer
- KOS-ADLS ≥ 65%
- Effusion < 2+</td></tr>
<tr><th colspan="3">Treatment Strategies:</th></tr>
<tr><td rowspan="7">Total Visits:
5-6 visits

PT Frequency:
2x per week

HEP Frequency:
4-6x per day</td><td>ROM:</td><td>- Continuation of previous phase exercises
- Add bag/prone hangs with light weight if lacking full knee extension for low load long duration stretch</td></tr>
<tr><td>Muscle Performance:</td><td>Quadriceps strengthening (90-0°)
- Open kinetic chain (OKC): multi-angle isometrics, LAQ with cuff weights/resistance band/knee extension machine, variable range isokinetics

Global Lower Extremity Strengthening
- Closed kinetic chain (CKC): wall sits, air squats
- Accessory strengthening: core, hip and calf strengthening, hamstring curls (appendix 1: Precautions and concomitant procedure modifications)
- Optional: BFR strength training</td></tr>
<tr><td>Neuro Re-education:</td><td>- Weight shifts and single leg balance, FES if poor quad control</td></tr>
<tr><td>Manual Therapy:</td><td>- Incision mobilizations PRN (once healed), patellar mobilizations, flexion/extension stretching</td></tr>
<tr><td>Electric Stimulation:</td><td>- NMES dosed @ ≥ 50% of isometric MVIC (appendix 5)</td></tr>
<tr><td>Gait Training:</td><td>- Cue “land on bent knee, push knee back while squeezing quad,” retro walking to promote TKE, progress to functional brace as swelling permits (if used)</td></tr>
<tr><td>Modalities:</td><td>- Continue for effusion management</td></tr>
<tr><td colspan="3">Criteria to discontinue crutches: Normal gait pattern with good active quad control, no lag with SLR and effusion ≤ 2+

Effusion monitoring: Assess response to exercises frequently, stay same intensity or decrease if effusion increases; do not progress exercise with a 2+ effusion. Refer to Soreness Rules (Appendix 2)

Pain monitoring: Modifications to exercise ROM and load to minimize quad and patellar tendon graft site irritation (keep pain < 5/10)

Home Exercise Program Recommendations:
Quad sets 5-10 sets of 100 x 5-10” per day, SLR (assisted as needed) 3 x 10, LAQ (90-0°) with resistance 30 x 5”, heel slides/seated assisted knee flexion/wall slides 30 x 5”, heel prop with ice 5 x 10 minutes per day, self-mobilizations of patella 20 x 5” each direction, frequent short bouts of ambulation (3-5 minutes/hour)</td></tr>
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<table>
<tr><th colspan="3">Intermediate Post-Operative Phase (week 4-6)</th></tr>
<tr><td colspan="2">Phase Goals:
- Complete impairment resolution
- Progressive quadriceps strengthening
- Restoration of full ROM
- Resumption of ADLs</td><td>Milestones:
- Flexion ROM within 10° of uninvolved limb
- Quad strength MVIC ≥ 60% of uninvolved
(See Comment Below)
- Effusion ≤ 1+
- Normal gait pattern
- Reciprocal stair climbing</td></tr>
<tr><th colspan="3">Treatment Strategies:</th></tr>
<tr><td rowspan="8">Total Visits:
11-12 visits

PT Frequency:
2x per week

HEP Frequency:
1-2x per day</td><td>ROM/Manual Therapy:</td><td>- PRN for knee ROM and mobility deficits
- Formally assess hip and ankle for impairments</td></tr>
<tr><td>Muscle Performance:</td><td>Quadriceps strengthening (90-0°)
- OKC: Progressive isokinetics (e.g. speed and ROM), knee extension machine

Global Lower Extremity Strengthening
- CKC: leg press, single leg squats, step ups/downs, forward and side lunges, bridges
- Accessory Strengthening: core, hip and calf strengthening, hamstring curl machine (appendix 1)
- Optional: BFR Strength Training (discontinue when able to tolerate >70% 1-RM load)</td></tr>
<tr><td>Neuro Re-education:</td><td>- Balance and proprioceptive activities on variable surfaces (e.g. BOSU, foam), perturbation progressions</td></tr>
<tr><td>Aerobic Training:</td><td>- Bike, elliptical, stair master (10 minutes minimum)</td></tr>
<tr><td>Electric Stimulation:</td><td>- NMES dosed @ ≥ 50% of isometric MVIC (see appendix 5)</td></tr>
<tr><td>Gait Training:</td><td>- PRN for remaining abnormalities</td></tr>
<tr><td>Modalities:</td><td>- PRN for pain and effusion</td></tr>
<tr><td colspan="3">Effusion monitoring and Pain Monitoring: Continue as outlined above

Preferred methods for assessing quad strength: Isokinetic dynamometer (e.g. Biodex) in isometric or isokinetic (60/90/120 degrees/sec) mode, handheld dynamometry with fixation or 1 repetition maximum on a knee extension machine 90-45° or 90°-0° (week 7+)

Quadriceps Strength Index (QI): Monitor for bilateral strength loss after injury. QI should be calculated using pre-injury data for the uninvolved (if available) or the highest value collected during rehab to avoid overestimating quadriceps strength in the involved limb.

Home Exercise Program Recommendations:
SLR with resistance 3 x 10, LAQ with resistance 30 x 5”, prone quad stretch 3 x 30”, SLS 10 x 15”, squats (0-90°) 3 x 10, heel raises 3 x 10, self-patellar mobs PRN 20 x 5”, aerobic conditioning 10-15 minutes, step ups 3 x 10, single leg squat eccentrics 3 x 10, planks 5 x 30”, hip strengthening 3 x 10</td></tr>
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<tr><th colspan="3">Late Post-Operative Phase (week 7-9)</th></tr>
<tr><td colspan="2">Phase Goals:
- Improve tolerance to loading
- Improve aerobic conditioning
- Increase variability
- Improve ADL function and efficiency</td><td>Milestones:
- Full and symmetrical ROM
- Quad strength ≥ 70% of uninvolved
- Effusion ≤ 1+
- Normal gait pattern
- KOS-ADLS ≥ 70%</td></tr>
<tr><th colspan="3">Treatment Strategies:</th></tr>
<tr><td rowspan="7">Total Visits:
17-18 visits

PT Frequency:
2x per week

HEP Frequency:
2-3x per week</td><td>Muscle Performance:</td><td>Concentric and eccentric overload @ 60-75% 1-RM
Quadriceps (90-0°), posterior chain and accessory strengthening:
- Knee extension machine, leg press, SL variations, hamstring curls, weighted step ups and lunges</td></tr>
<tr><td>Neuro Re-education:</td><td>- Perturbation training and higher-level balance progressions (e.g. multi-task, ball toss, incorporate sport specific equipment as appropriate)</td></tr>
<tr><td>Aerobic Training:</td><td>- Increase duration and intensity</td></tr>
<tr><td>Electric Stimulation:</td><td>- May discontinue if quad strength ≥ 80%</td></tr>
<tr><td>Gait Training:</td><td>- PRN for remaining abnormalities</td></tr>
<tr><td>Modalities:</td><td>- PRN for pain and effusion</td></tr>
<tr><td colspan="3">Exercise Constraints:
External load constraints for strengthening examples:
- 1-RM percentage: 65-85% of 1-RM, 5-8 reps, 3-5 sets
- 5-RM percentage: 80-100% of 5-RM, 5-8 reps, 3-5 sets
- Rate of loading/tempo: 3-5 second concentric, 0-2 second pause at transition, 3-5 second eccentric (Silbernagel 2017)
- Work/rest ratio: 3-4 minutes between sets (variable based on exercise goal)
Internal load constraints for strengthening examples:
- Rate of perceived exertion: working sets at 6-8/10 RPE scale
- Repetitions in reserve (RIR): prescribe load in which patient can complete 5-8 reps through prescribed ROM with a theoretical ability to complete 2-3 additional reps before maximal fatigue. If upon completion of set the patient reports RIR is ≥ 3-4 repetitions, increase load
- Daily Adjustable Progressive Resistive Exercise (DAPRE) method: utilizes working weight and maximal number of reps completed during set to determine load adjustments (see Knight 1979)

Home Exercise Program Recommendations:
Resisted squats (0-90°) 5 x 8, LAQ with heavy resistance 3 x 15, unilateral heel raises 3 x 10, aerobic conditioning 15-30 minutes, resisted step ups 3 x 10, SL squats 3 x 10, planks 5 x 60”, resisted SL RDLs 3 x 12, hip strengthening 3 x 10</td></tr>
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Transitional Phase I (week 10-12)		
Phase Goals: - Initiate transition to gym-based program and/or supervised training with ATC or strength coach if appropriate		**Milestones:** - Full and pain free ROM - Quad strength ≥ 75% of uninvolved - Effusion ≤ 1+ - KOS-ADLS ≥ 80%
Treatment Strategies:		
Total Visits: **20-24 visits** **PT Frequency:** **1-2x per week** **HEP Frequency:** **2-3x per week**	Muscle Performance:	Concentric and eccentric overload @ 60-85% 1-RM *Progressive quadriceps and lower extremity strength training:* - Knee extension machine, deadlifts, barbell squatting, light leg press/shuttle plyometrics (week 12+)
	Neuro Re-education:	- Higher-level balance progressions (e.g. reactive vs anticipatory, incorporate sport specific equipment as appropriate)
	Aerobic Training:	- Initiate Alter-G or pool running
	Electric Stimulation:	- May discontinue if quad strength ≥ 80%
	Modalities:	- PRN for pain and effusion

Transitional Phase II (week 13-16)		
Phase Goals: - Initiate running - Transition to gym-based program and/or supervised training with ATC or strength coach if appropriate		**Milestones:** - Quad strength ≥ 80% of uninvolved - Effusion ≤ trace - No pain or swelling with running
Treatment Strategies:		
Total Visits: **24-32 visits** **PT Frequency:** **1-2x per week**	Muscle Performance:	Concentric and eccentric overload @ 60-85% 1-RM *Progressive quadriceps and lower extremity strength training:* - Light power training (e.g. cleans, snatches), circuit training
	Neuro Re-education:	- Controlled landing mechanics (begin with 2" box drops) and higher-level balance progressions as appropriate
	Aerobic Training:	- Continue Alter-G or pool running, progress duration and intensity as appropriate
HEP Frequency: **2-3x per week**	**Return to Level Ground Running Criteria:** - Quadriceps strength ≥ 80% - Effusion ≤ trace - Understanding of soreness rules Appendix 1 for considerations specific to allografts Appendix 6 for full running progression	

Transitional Phase III (months 4-6)

Phase Goals:	**Milestones:**
- Initiate sprint progression - Initiate agilities - Initiate jumping - Initiate Secondary Prevention Program	- Quad strength ≥ 85% of uninvolved - Hop testing ≥ 85% - KOS-ADLS ≥ 85% - ACL RSI > 60% (at 6 months)

Treatment Strategies:

Total Visits: **27-38 visits**	Muscle Performance:	Concentric and eccentric overload @ 60-85% 1-RM *High intensity strength training:* - Heavy barbell squats, deadlifts, kettlebell swings, Nordic hamstring curls, lateral sled pulls
PT Frequency: **1-2x per month** **HEP Frequency:** **3-4x per week**	**Stage 1 Sprint Progression Criteria:** - Quadriceps strength ≥ 80% - Effusion ≤ trace - Understanding of soreness rules - Completion of running progression Appendix 8 for Stage 1 Sprint Progression	
Supervised by ATC or Strength Coach if able	**Return to Agilities Criteria (e.g. forward and lateral cone shuttle, figure-8)** *Progress from pre-planned to reactive, include sports specific equipment as appropriate* - Quadriceps strength ≥ 80% - Effusion ≤ trace - Hop testing ≥ 80% (appendix 7) - Understanding of soreness rules - Completion of running and Stage 1 Sprint Progression Appendix 1 for considerations specific to allografts	
	Return to High Intensity Plyometrics (e.g. box jump, drop jumps, broad jump): *Progress from two-feet landing to one-foot landing, single plane to multiplanar* - Quadriceps strength ≥ 85% - Effusion ≤ trace - Hop testing ≥ 85% (appendix 7) - Completion of running progression - Completion of Stage 1 Sprint Progression No apprehension with light agilities	

Home Exercise Program Recommendations:

Individualized based on specific sport and patient needs. Ensure the demand is sufficient to improve the working capacity with sport specific skills.

Ex: Soccer player (not fully-inclusive)

Strength Training (2-3x per week):

- Unilateral and bilateral knee extension, 5 x 5 @ 60-85% 1-RM
- Kettlebell/dumbbell squats, 3 x 12
- Single leg squat with heel raises, 3 x 12
- Single leg RDLs with kettlebell, 3 x 12
- Rearfoot elevated split squats with dumbbells, 3 x 10
- Nordic hamstring curls, 3 x 7
- Copenhagen planks, 3 x 30”

Aerobic Conditioning (3-4x per week):

- Aerobic training on level ground or treadmill, 20-30 minutes continuous
- Tempo runs on track or soccer field
- Speed ladders on sport specific surface (e.g. grass, turf)
- Short burst acceleration/deceleration cone drills with soccer ball

<table>
<tr><th colspan="3">Transitional Phase IV (months 6-9)</th></tr>
<tr><td colspan="2">Phase Goals:
- Sport specific skill acquisition
- Restoration of conditioning level to pre-injury level</td><td>Milestones:
- Quad strength ≥ 90-100% of uninvolved
- Hop testing ≥ 90%
- KOS-ADLS ≥ 90%
- ACL RSI ≥ 70%
- No effusion or pain with running, sprinting or agilities</td></tr>
<tr><th colspan="3">Treatment Strategies:</th></tr>
<tr><td rowspan="5">Total Visits:
31-46 visits

PT Frequency:
1-2x per month

HEP Frequency:
3-4x per week

Supervised by ATC or Strength Coach if able</td><td>Muscle Performance:</td><td>- High intensity power training and maximal effort strength training</td></tr>
<tr><td>Agility Training:</td><td>- 80-100% intensity, reactive, unpredictable and sport specific</td></tr>
<tr><td>Sport Specific Training:</td><td>- Individualized to sport/position, incorporate sport specific equipment and environments as able</td></tr>
<tr><td>Dynamic Anaerobic/Aerobic Training:</td><td>- Maximal effort sled push/pull and circuit training</td></tr>
<tr><td colspan="2">Stage 2 Sprint Progression Criteria:
- Quadriceps strength ≥ 90%
- Effusion ≤ trace
- Hop testing ≥ 90% (Appendix 7)
- Completion Stage 1 sprint progression
- No apprehension with moderate to high level agilities
Appendix 8 for Stage 2 Sprint Progression</td></tr>
<tr><td colspan="2">Return to Cutting and Pivoting Criteria:
- Quadriceps strength ≥ 90%
- Effusion ≤ trace
- Hop testing ≥ 90% (Appendix 7)
- No apprehension with moderate to high level agilities
- Completion of Stage 1 and 2 sprint progression
Appendix 1 for considerations specific to allografts</td></tr>
<tr><td colspan="2">Stage 3 Sprint Progression Criteria:
- Quadriceps strength ≥ 90%
- Effusion ≤ trace
- Hop testing ≥ 90% (Appendix 7)
- No apprehension with moderate to high level agilities
- Completion of Stage 2 sprint progression
Appendix 8 for Stage 3 Sprint Progression</td></tr>
</table>

<table>
<tr><th colspan="2">Return to Sport Phase V (months 9-12)</th></tr>
<tr><td>Phase Goals:
- Sport specific skill acquisition
- Build confidence during play with opponents
- Continuation of Secondary Prevention</td><td>Milestones:
- At least 9 months post-op (allografts 12+ months)
- Quad strength ≥ 90% of uninvolved (level 1 athletes ≥ 100%)
- Hop testing ≥ 90%
- KOS-ADLS ≥ 90%
- ACL RSI ≥ 80%
- IKDC > 76
- Marx Activity Scale < 9</td></tr>
<tr><th colspan="2">Treatment Strategies:</th></tr>
<tr><td rowspan="3">Total Visits:
35-50 visits

PT Frequency:
1-2x per month or until all RTS criteria is met
Injury

Prevention HEP Frequency:
2-3x per week</td><td>Return to Competition Progression:
- Non-contact practice
- Small sided contact practices (1v1, 2v2, 3v3)
- Full Practice
- Return to competition with restricted workload
- Return to competition unrestricted
*All without apprehension, pain, instability, effusion or compensations</td></tr>
<tr><td>ACL Secondary Prevention Program:
- 2x per week moving forward
- Maintain quadriceps strength and periodically assess with 1-RM knee extension strength test (pre/post season)
- See Knee Injury Prevention CPG for guidelines and video examples
- Consider long term implementation of Copenhagen planks and Nordic hamstring curls for lower extremity injury risk reduction strategies
If functional ACL Brace is used: may discontinue use after 1 year</td></tr>
<tr><td>Additional Consideration:
- No effusion, pain or apprehension with sport specific training and practice progressions
- Return to pre-injury conditioning level
- Minimal to no dynamic knee valgus with jumping and landing
- Hamstring/quadriceps ratio
- Vertical hop symmetry assessment</td></tr>
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Appendix 1: Precautions and Concomitant Procedure Modifications:	
Procedure:	Rehab Modification:
Patellar Tendon Autograft (BPTB):	- Be aware of patellofemoral forces and possible irritation during progressive resistive exercises (PRE's) - Treat anterior knee pain PRN with noxious e-stim, patellar taping; consider modifications of strength program (treat as tendinopathy using Pain Monitoring Model) - Consider alteration of knee flexion angle to most comfortable between 45°-60° for MVIC and NMES treatments - Initial Burst test at 12 weeks if no pain < 5/10
Hamstring Tendon Autograft:	- Begin isometric knee flexion no earlier than week 6 - Begin dynamic knee flexion no earlier than week 8, dynamic knee flexion with load and pain free 0-90° week 8-12 weeks - No hamstring restrictions beyond 12 weeks - Delay plyometrics until 16 weeks
Quad Tendon Autograft:	- Similar to BPTB and tendinopathy protocols, slower to regain quad strength - Modify hip angle (minimize hip flexion) to focus on strengthening of the rectus femoris
Allografts:	- Slower graft incorporation, therefore, slower progression to running, jumping, cutting and pivoting - Ensure all objective criteria is satisfied prior to progression - Delay return to level 1 sport until all criteria met and 1 year post-operative
Partial Meniscectomy:	- No modifications required; progress per patient tolerance and protocol
Meniscal Repair:	- Simple Repair: • WBAT in brace locked in full extension or knee immobilizer immediately for 4 weeks • ROM progression: 0-90° by week 2, progress as tolerated thereafter - Complex or Root Repair: • NWB in knee immobilizer for 6 weeks • ROM progression: 0-90° by week 2, progress as tolerated thereafter • Progress to full weight bearing by week 9 • Initiate CKC PRE at week 9 • Weight bearing flexion limited 0-45° weeks 8-12, 0-70° through week 16 • No isolated hamstring strengthening for 16 weeks - Resume standard ACL protocol after 16 weeks - Seated isokinetic and multi angle quadriceps isometric can substitute for weight-bearing exercises early on

Concomitant Abrasion Chondroplasty:	- WBAT with axillary crutches 3-5 days No modifications required, progress per patient tolerance and protocol
Concomitant Microfracture:	- NWB 2-4 weeks with axillary crutches - No weightbearing activities in treatment for 4 weeks **Consider location and size of lesion for exercise specific alterations**
Chondral Repair (OATS, ACI, MACI):	- Follow procedure specific protocol if done concomitantly
Meniscal Transplantation:	- Follow procedure specific protocol if done concomitantly
Concomitant MCL Injury:	- Restrict motion to sagittal plane until week 4-6 to allow healing of MCL - Perform PRE's with tibia in internal rotation during early post-op period to decrease MCL stress - Consider brace for exercise and periods of activity if severe sprain and/or patient has pain - Post-operative concomitant MCL Repair: • PWB locked in extension for 1-2 weeks • Unlock brace with weightbearing at week 2-6 and wean from brace and assistive devices • ROM restrictions: flexion ROM 0-90°, progress as tolerated thereafter • Avoid exercises resulting in valgus stress at knee
LCL Injury:	- Follow LCL rehabilitation guidelines (Not ACL protocol)
PCL injury:	- Follow PCL rehabilitation guidelines (Not ACL protocol)
Posterolateral Corner Repair:	- Minimize external rotation torques and varus stress 6-8 weeks - Avoid hyper-extension - No resisted knee flexion for 12 weeks
ACL Revision:	- Delay progression of running, hop testing and agility drills by 4 weeks - Crutches and immobilizer will be used 2 weeks following surgery - Delay return to sport beyond 12 months

Appendix 2: Measuring Effusion: Sweep Test	
Instructions:	1. Milk out swelling distal to proximal several times along the medial aspect of the knee 2. Sweep proximal to distal on the lateral aspect of knee 3. View the medial sulcus for return of swelling
Grade Zero:	None
Grade Trace:	Small amount returns
Grade 1+:	Can milk out the swelling and it **does not** return on its own but returns with lateral sweep
Grade 2+:	Can milk out the swelling and it **returns immediately** to fill the pouch
Grade 3+:	**Cannot** milk swelling out
Rules: 1. Patients should not progress in their exercise program when the effusion is > 1+ 2. When patients are **holding** anything above a 2+ for prolonged periods, contact MD 3. Any drastic changes of 2 grades or appearance of effusion when it was absent, decrease activity and gradually reintroduce activity when possible	
Modified with permission from JOSPT. Adams D, Logerstedt D, Hunter-Giordano A, Axe MJ, Snyder-Mackler L. Current concepts for anterior cruciate ligament reconstruction: A criterion-based rehabilitation progression. *J Orthop Sports Phys Ther*. 2012;42(7):601-614. doi:10.2519/jospt.2012.3871	

Appendix 3: Soreness Rules	
Criterion:	Action:
Soreness during warm-up that continues	2 days off, drop down 1 level
Soreness during warm-up that goes away	Stay at same level that led to soreness
Soreness during warm-up that goes away but redevelops during session	2 day off, drop down 1 level
Soreness the day after lifting (not muscular soreness)	1 day off, do not advance program to next level
No Soreness	Advance 1 level per week or as instructed by healthcare professional
Modified with permission from JOSPT. Adams D, Logerstedt D, Hunter-Giordano A, Axe MJ, Snyder-Mackler L. Current concepts for anterior cruciate ligament reconstruction: A criterion-based rehabilitation progression. *J Orthop Sports Phys Ther*. 2012;42(7):601-614. doi:10.2519/jospt.2012.3871	

Appendix 4: Non-weight Bearing Quadriceps Exercise Recommendations	
	All exercises completed 90-0°:
Weeks 0-2	LAQ: No/light resistance: 10-15 reps, 2-3 sets, tempo 3-1-3
Weeks 2-3	LAQ: Heavy cuff weights/Knee Extension Machine, 10-15 reps, 2-3 sets, tempo 3-1-3
Weeks 4-6	LAQ: Knee extension machine, 15-20 reps, 2-3 sets, tempo 3-1-3
Weeks 7-9	Knee extension machine: single leg/eccentrics, 15-20 reps, 2-3 sets, tempo 3-1-3
Weeks 10-12	Knee extension machine: single leg/eccentrics, 8-12 reps @ 60-85% 1 RM, 2-3 sets
Weeks 13-16+	Knee extension machine: single leg/eccentrics, 5-8 reps, 4-5 sets, 75-90% 1 RM
May consider BFR Training to volitional failure if higher loading is not tolerated well	
Progress load and exercise volume based on knee joint effusion and soreness rules	

Appendix 5: Neuromuscular Electric Stimulation for Quadriceps Strengthening	
NMES Guidelines:	
1. Electrodes placed over proximal lateral quadriceps and distal medial quadriceps (modify distal electrode placement until portal is healed)	
2. Stimulation parameters: 400 micro sec pulse width, 75 pulses/sec, 2 sec. ramp up, 12 sec. on, 50 sec. rest, intensity to max tolerable [**at least 50% MVIC**] 15 contractions per session, 3 sessions per week until quadriceps strength MVIC is 80% of uninvolved	
3. Stimulation performed **isometrically** at **60°** (if patellar or quad tendon graft, consider beginning NMES at 45° knee flexion and progressing angle to 60° as tendon pain subsides)	
Maximum Volitional Isometric Contraction (MVIC): Patient is asked to volitionally extend the involved leg as hard as possible while knee is maintained isometrically at 60° knee flexion - Side to side comparison: (involved/uninvolved X 100 = % MVIC) - NMES dosed at ≥ 50% of MVIC	

Appendix 6: Running Progression		
	Treadmill	**Track**
Level 1	0.1 mile walk / 0.1 mile jog, repeat 10 times	Jog straights / walk curves (2 miles)
Level 2	0.1 mile walk / 0.2 mile jog - 2 miles total	Jog straights / jog 1 curves every other lap (2 miles)
Level 3	0.1 mile walk / 0.3 mile jog - 2 miles total	Jog straights / jog 1 curve every lap (2 miles)
Level 4	0.1 mile walk / 0.4 mile jog - 2 miles total	Fast walk 1 ¾ lap / walk curve (2 miles)
Level 5	Jog full 2 miles	Jog full 2 miles
Level 6	Increase workout to 2 ½ miles	Increase workout to 2 ½ miles
Level 7	Increase workout to 3 miles	Increase workout to 3 miles
Level 8	Alternate between running/jogging every ¼ mile	Increase speed on straights / jog curves
Instructions: - Mandatory 2-day rest between workouts for first two week - Do not advance more than 2 levels per week - Two days rest mandatory between levels 1, 2, and 3 workouts - One day rest mandatory between levels 4-8 workouts		
Soreness Rules: - If sore during warm-up, take 2 days off and drop down 1 level - If sore during workout, take 1 day off and drop down 1 level - If sore after workout, stay at same level		
Specific Considerations: - Non-endurance athletes: must successfully complete level 4 of progression before advancement to sprinting		
Modified with permission from JOSPT. Adams D, Logerstedt D, Hunter-Giordano A, Axe MJ, Snyder-Mackler L. Current concepts for anterior cruciate ligament reconstruction: A criterion-based rehabilitation progression. *J Orthop Sports Phys Ther*. 2012;42(7):601-614. doi:10.2519/jospt.2012.3871		

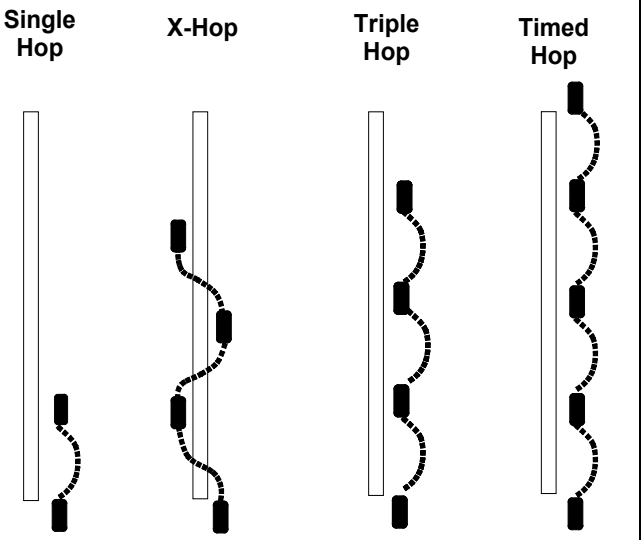
Appendix 7: Hop Testing

Purpose: Objective function testing of the lower extremity aids in determining functional limitations of the knee joint during sports activities.

Selection of Questions:
Four one-legged function tests comprise the objective function testing (completed in order):

1. Single hop (distance)
2. Cross-over hop (distance)
3. Triple hop (distance)
4. Timed hop

Complete one warm up trial on each limb, beginning with the uninvolved side



Materials Needed:
1. One stopwatch
2. One tape measure
3. Standard marking tape

Test Descriptions:

1. Single hop (distance)	The distance a patient travels in one hop on a single leg is recorded. Each patient is allowed one trial for each leg, and then performs two hops per leg.
2. Cross-over hop (distance)	A six-meter line six inches wide is marked with tape. The patient performs three hops on one leg, crisscrossing the line with each hop. Each test is completed twice on each leg, with the total distance hopped measured.
3. Triple hop (distance)	The patient performs a series of three hops on one leg, with the total distance hopped measured. The test is performed twice on each leg.
4. Timed hop (6 m)	Measure a distance of six meters, marking start and finish lines with tape. A technician stands at the finish line to time the subjects with a stopwatch. At the word “go”, the patient begins a series of one-legged hops from the starting line to the finish line. Patients are encouraged to use large forceful hopping motions, not a series of small hops, to complete the course. Each patient completes a slow trial on each leg. A series of two tests per leg are then completed. Two tests are first completed on the non-involved leg, followed by two tests on the involved leg.
Interpretation:	The mean is taken from the two tests performed on each leg. Then, the percent deficit between limbs is calculated.

Noyes FR, Barber SD, Mangine RE. Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *Am J Sports Med.* 1991;19(5):513-518. doi:10.1177/036354659101900518

Appendix 8a: Criteria-based Return to Sprinting Progression			
Stage 1: 50% Intensity (1:3 work to rest ratio)			
Objective: Build work capacity for anaerobic conditioning/endurance			
Step 1	**Step 2**	**Step 3**	**Step 4**
20 yd x 3 untimed	20 yd x 4 untimed	20 yd x 3	20 yd x 3
40 yd x 2 untimed	40 yd x 3 untimed	40 yd x 4	40 yd x 4
60 yd x 2 untimed	60 yd x 2 untimed	60 yd x 2	60 yd x 2
80 yd x 2 untimed	80 yd x 2 untimed	80 yd x 2	80 yd x 2
100 yd x 1 untimed	100 yd x 1 untimed	100 yd x 1	100 yd x 2
80 yd x 2 untimed	80 yd x 2 untimed	80 yd x 2	80 yd x 1
60 yd x 2 untimed	60 yd x 2 untimed	60 yd x 2	60 yd x 2
40 yd x 2 untimed	40 yd x 3 untimed	40 yd x 4	40 yd x 4
20 yd x 3 untimed	20 yd x 4 untimed	20 yd x 3	20 yd x 3
19 runs @ 940 yd	23 runs @ 1060 yd	23 runs @ 1100 yd	23 runs @ 1120 yd
Qualifier: Gradual build in acceleration from starting line with slow, controlled deceleration beyond end line			
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Appendix 8b: Criteria-based Return to Sprinting Progression			
Stage 2: 75% Intensity (1:5 work to rest ratio)			
Objective: Speed development, improve technique and build repeated sprint ability			
Step 1	**Step 2**	**Step 3**	**Step 4**
20 yd x 3	20 yd x 3	20 yd x 2	20 yd x 2
40 yd x 2	40 yd x 2	40 yd x 2	40 yd x 2
60 yd x 2	60 yd x 1	60 yd x 1	60 yd x 2
80 yd x 1	80 yd x 1	80 yd x 1	80 yd x 1
100 yd x 1	100 yd x 1	100 yd x 1	60 yd x 2
80 yd x 1	80 yd x 1	80 yd x 1	40 yd x 2
60 yd x 2	60 yd x 1	60 yd x 1	20 yd x 2
40 yd x 2	40 yd x 2	40 yd x 2	
20 yd x 3	20 yd x 3	20 yd x 2	
17 runs @ 780 yd	15 runs @ 660 yd	13 runs @ 620 yd	13 runs @ 560 yd
Qualifier: Rapid build in acceleration from starting line with moderate deceleration beyond end line			
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Appendix 8c: Criteria-based Return to Sprinting Progression			
Stage 3: 90-100% Intensity (1:7 work to rest ratio)			
Objective: Achieve maximum effort. Work:rest ratio should replicate sport demands in step 3 and 4			
Step 1	**Step 2**	**Step 3**	**Step 4**
20 yd x 6	10 yd x 3	10 yd x 3	10 yd x 2
40 yd x 2	20 yd x 4	20 yd x 3	20 yd x 3
60 yd x 1	40 yd x 2	30 yd x 2	30 yd x 2
40 yd x 2	60 yd x 1	40 yd x 2	40 yd x 1
20 yd x 6	40 yd x 2	60 yd x 1	60 yd x 1
10 yd x 3	30 yd x 1	30 yd x 2	40 yd x 1
	20 yd x 4	20 yd x 3	30 yd x 2
	10 yd x 2	10 yd x 3	20 yd x 3
*Full subjective recovery	*Full subjective recovery		10 yd x 2
20 runs @ 490 yd	19 runs @ 460 yd	19 runs @ 440 yd	17 runs @ 420 yd
Qualifier: Maximal build in acceleration from starting line with moderate deceleration beyond end line			
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References:

1. Adams D, Logerstedt D, Hunter-Giordano A, Axe MJ, Snyder-Mackler L. Current concepts for anterior cruciate ligament reconstruction: A criterion-based rehabilitation progression. *J Orthop Sports Phys Ther*. 2012;42(7):601-614. doi:10.2519/jospt.2012.3871

2. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2009;41(3):687-708. doi:10.1249/MSS.0b013e3181915670

3. Anthony Sinacore J, Evans AM, Lynch BN, Joreitz RE, Irrgang JJ, Lynch AD. Diagnostic accuracy of handheld dynamometry and 1-repetitionmaximum tests for identifying meaningful quadriceps strength asymmetries. *J Orthop Sports Phys Ther*. 2017;47(2):97-107. doi:10.2519/jospt.2017.6651

4. Arnold T, Shelbourne KD. A perioperative rehabilitation program for anterior cruciate ligament surgery. *Phys Sportsmed*. 2000;28(1):31-44. doi:10.3810/psm.2000.01.621

5. Arundale AJH, Bizzini M, Giordano A, et al. Exercise-based knee and anterior cruciate ligament injury prevention. *J Orthop Sports Phys Ther*. 2018;48(9):A1 A25. doi:10.2519/jospt.2018.0303

6. Arundale AJH, Capin JJ, Zarzycki R, Smith AH, Snyder-Mackler L. Two Year Acl Reinjury Rate of 2.5%: Outcomes Report of the Men in a Secondary Acl Injury Prevention Program (Acl-Sports). *Int J Sports Phys Ther*. 2018;13(3):422-431. doi:10.26603/ijspt20180422

7. 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

8. 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

9. 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

10. Dean RS, DePhillipo NN, Monson JK, LaPrade RF. Peripheral Stabilization Suture to Address Meniscal Extrusion in a Revision Meniscal Root Repair: Surgical Technique and Rehabilitation Protocol. *Arthrosc Tech*. 2020;9(8):e1211-e1218. Published 2020 Aug 7. doi:10.1016/j.eats.2020.04.022

11. 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

12. Englander ZA, Garrett WE, Spritzer CE, DeFrate LE. In vivo attachment site to attachment site length and strain of the ACL and its bundles during the full gait cycle measured by MRI and high-speed biplanar radiography. *J Biomech*. 2020;98:109443. doi:10.1016/j.jbiomech.2019.109443

13. 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

14. 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

15. 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

16. 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

17. Goodstadt NM, Hunter-Giordano A, Axe MJ, Snyder-Mackler L. Functional testing to determine readiness to discontinue brace use, one year after acl reconstruction. *Int J Sports Phys Ther*. 2013;8(2):91-96.

18. 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

19. 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

20. Harøy J, Thorborg K, Serner A, et al. Including the Copenhagen Adduction Exercise in the FIFA 11+ Provides Missing Eccentric Hip Adduction Strength Effect in Male Soccer Players: A Randomized Controlled Trial. *Am J Sports Med*. 2017;45(13):3052-3059. doi:10.1177/0363546517720194

21. Irrgang JJ, Fitzgerald GK. Rehabilitation of the multiple-ligament-injured knee. *Clin Sports Med*. 2000;19(3):545-571. doi:10.1016/s0278-5919(05)70223-4

22. Johnson JL, Capin JJ, Arundale AJH, Zarzycki R, Smith AH, Snyder-Mackler L. A Secondary Injury Prevention Program May Decrease Contralateral Anterior Cruciate Ligament Injuries in Female Athletes: 2-Year Injury Rates in the ACL-SPORTS Randomized Controlled Trial. *J Orthop Sports Phys Ther*. 2020;50(9):523-530. doi:10.2519/jospt.2020.9407

23. Knight KL. Knee rehabilitation by the daily adjustable progressive resistive exercise technique. *Am J Sports Med*. 1979;7(6):336-337. doi:10.1177/036354657900700605

24. Krzysztofik M, Wilk M, Wojdała G, Gołaś A. Maximizing muscle hypertrophy: A systematic review of advanced resistance training techniques and methods. *Int J Environ Res Public Health*. 2019;16(24). doi:10.3390/ijerph16244897

25. Lesinski M, Prieske O, Granacher U. Effects and dose-response relationships of resistance training on physical performance in youth athletes: A systematic review and meta-analysis. *Br J Sports Med*. 2016;50(13):781-795. doi:10.1136/bjsports-2015-095497

26. Logerstedt D, Lynch A, Axe MJ, Snyder-Mackler L. Pre-operative quadriceps strength predicts IKDC2000 scores 6 months after anterior cruciate ligament reconstruction. *Knee*. 2013;20(3):208-212. doi:10.1016/j.knee.2012.07.011

27. Lorenz D, Domzalski S. CRITERIA-BASED RETURN TO SPRINTING PROGRESSION FOLLOWING LOWER EXTREMITY INJURY. *Int J Sports Phys Ther*. 2020;15(2):326-332.

28. Maupin D, Schram B, Canetti E, Orr R. The Relationship Between Acute: Chronic Workload Ratios and Injury Risk in Sports: A Systematic Review . *Open Access J Sport Med*. 2020;Volume 11:51-75. doi:10.2147/oajsm.s231405

29. Morishita S, Tsubaki A, Takabayashi T, Fu JB. Relationship between the rating of perceived exertion scale and the load intensity of resistance training. *Strength Cond J*. 2018;40(2):94-109. doi:10.1519/SSC.0000000000000373

30. 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

31. Reiman MP, Lorenz DS. Integration of strength and conditioning principles into a rehabilitation program. *Int J Sports Phys Ther*. 2011;6(3):241-253.

32. Roldán E, Reeves ND, Cooper G, Andrews K. In vivo mechanical behaviour of the anterior cruciate ligament: A study of six daily and high impact activities. *Gait Posture*. 2017;58:201-207. doi:10.1016/j.gaitpost.2017.07.123

33. 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

34. Shelbourne KD, Nitz P. Accelerated rehabilitation after anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*. 1992;15(6):256-264. doi:10.2519/jospt.1992.15.6.256

35. Silbernagel KG, Thomeé R, Eriksson BI, Karlsson J. Continued sports activity, using a pain-monitoring model, during rehabilitation in patients with Achilles tendinopathy: a randomized controlled study. *Am J Sports Med*. 2007;35(6):897-906. doi:10.1177/0363546506298279

36. van Dyk N, Behan FP, Whiteley R. Including the Nordic hamstring exercise in injury prevention programmes halves the rate of hamstring injuries: a systematic review and meta-analysis of 8459 athletes. *Br J Sports Med*. 2019;53(21):1362-1370. doi:10.1136/bjsports-2018-100045

37. Webster KE, Feller JA. Development and Validation of a Short Version of the Anterior Cruciate Ligament Return to Sport After Injury (ACL-RSI) Scale. *Ortho J Sport Med*. 2018;6(4):1-7. doi:10.1177/2325967118763763

38. White K, Di Stasi SL, Smith AH, Snyder-Mackler L. Anterior cruciate ligament-specialized post-operative return-to-sports (ACL-SPORTS) training: A randomized control trial. *BMC Musculoskelet Disord*. 2013;14(1):1. doi:10.1186/1471-2474-14-108

39. 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

40. Zourdos MC, Klemp A, Dolan C, et al. Novel Resistance Training–Specific Rating of Perceived Exertion Scale Measuring Repetitions in Reserve. *J Strength Cond Res*. 2016;30(1):267-275. doi:10.1519/JSC.0000000000001049