Insert Patient I.D. Label

ACL Reconstruction Rehabilitation Guidelines- Bone-Patellar Tendon-Bone (BPTB)

The following rehabilitation guidelines are based upon current scientific literature and our clinical experience in rehabilitation of athletes following Anterior Cruciate Ligament (ACL) reconstruction. The document is designed to guide rehabilitation only, and should not replace the clinical judgement of the instructing physiotherapist.

Rehabilitation following ACL reconstruction (ACL-R) should be gradual and progressive, and must be guided by symptoms, functional ability, tolerance, and specific consultant instructions. Objective criteria should be used to sanction from one phase to the next, from pre-habilitation to return to performance.

The proposed phases of the following protocol are not mutually exclusive. While rehabilitation priorities will differ through each phase, the prescribed rehabilitation programme should endeavour to maintain targets achieved in previous phases.

Suggested time frames are guidelines only, and while an athlete may appear fully rehabilitated in terms of strength and biomechanical performance, the graft ligamentization process (Claes et al 2014) will take a minimum of 9 - 12 months to reach graft maturation. This timeline must be respected to allow the greatest opportunity for return to play without recurrence.

<table>
<tr><th colspan="2">Phase 0: Prehabilitation</th></tr>
<tr><td colspan="2">Completion of a comprehensive prehabilitation programme prior to surgery has been shown to improve knee function both before and after surgery (Grindem et al., 2014). Physical and psychological preparation of the patient, and preparation of the injured knee joint is a critical step in successful rehabilitation. This preoperative phase also aims to reduce of the risk of postoperative complications and improve the likelihood of a successful return to high-level activity, minimising the risk of reinjury. (Wilk and Arrigo 2017).</td></tr>
<tr><td>Goals</td><td>- Full range of motion (ROM) (NB: Full extension)
- Elimination of knee joint effusion
- Overcome arthrogenic muscle inhibition
- Neuromuscular control restoration
- Familiarisation with post-operative exercises
- Education in preparation for surgery</td></tr>
<tr><td>Interventions</td><td>Education
- Familiarisation of the early post-operative exercises and the rehabilitation process
Swelling
- Cryotherapy, Compression, Elevation
ROM
Active Range of Motion (AROM) and Active Assisted Range of Motion (AAROM) flexion
- AROM and AAROM Extension
- Knee extensions with heel supported and knee unsupported
Muscle Activation</td></tr>
</table>

	- Restoration of pre-injury quadriceps strength as able - Restoration of pre-injury hamstring strength as appropriate IRQ, SLR, Open and Closed Chain Quadriceps activation, progressing load as tolerated **Neuromuscular/Proprioceptive Training** - Eliminate antalgic Gait Pattern - Retro Stepping Drills - Balance Training Drills - Single leg stance drills **Gait** - Normal walking pattern with full extension at heel strike, crutches if necessary to achieve this - Retro Walking
Progression Criteria (Surgery)	- Full Active Knee ROM - Calm Knee joint, free from swelling and pain - Normal gait pattern - Restoration of quadriceps/hamstring strength

Phase I (a)- Immediate Post-Operative Phase 0-10 days Regaining Mobility, Control and Optimal Strength	
The early post-operative phase focuses primarily on aggressive management of pain and swelling, restoration of quadriceps activation. Early restoration of full passive knee extension should be made a priority, while knee flexion can be allowed to return more gradually. Some hyperextension should be achieved in the immediate days following surgery.	
Goals	- Manage the graft donor site morbidity. I.e.- pain and swelling and wound healing - Restore full knee extension (including hyperextension by day 14) and Knee Flexion to 125+ degrees - Maximise quadriceps recruitment while minimizing AMI (Arthogenic muscle inhibition) caused by pain and swelling and quad atrophy - Increase weight bearing as tolerated with Elbow crutches and progress to a Full Weight bearing (FWB) with a normal gait pattern
Treatment Guidelines	**Patient education:** - Regarding the operation and recovery process, the graft and home management and exercises (van Grinsven et al. 2010) **Swelling** - Decrease swelling & pain with POLICE principles- Protection, Optimal loading, Ice, Compression, and Elevation. **Monitor and reduce risk of infection** - Wound cleaning and dressing - Look out for signs of infection such as redness, swelling, pus, fever **Range of Motion** - Active, active assisted and passive techniques. - Patella mobilisations can be used to aid restoration of full knee extension and flexion and to maintain patella mobility. **Neuromuscular Control** - Restore quadriceps recruitment using various unweighted open chain exercises including static quadriceps contractions, straight leg raise, inner range quadriceps exercises.

	- Maintain gluteal activation using static glute contractions, and once appropriate progressing to closed chain glute exercises - NMES indicated for patients with poor quads recruitment (Hauger et al. 2017). **Gait re-education** - Ensure correct gait patterns (+/- crutches), with full and equal weight bearing and full extension at heel strike - Active quadriceps strengthening is begun as a static co-contraction with hamstrings achieved through restoration of the normal gait cycle.
Progression Criteria	- Full Weight bearing - Normal gait pattern with/without assistive device - Full Active Extension (Including hyper-extension) - Active Knee flexion to 125+ degrees

Phase I b (2-16 weeks) Regaining Mobility, Control and Optimal Strength	
Eventual restoration of symmetrical range of motion should be achieved, as loss of range of motion is linked to poor outcomes functionally following ACLR. (Wilk and Arrigo 2017). In particular, restoration of knee hyperextension is crucial to the success of the rehabilitation process (Shelbourne and Gray, 2009). Restoration of hyper-extension should be judged on the uninjured joint where possible.	
Goals	- Maintain Extension (Hyperextension > 0 to 5/7 degrees) - Symmetrical flexion ROM - Overcoming residual post-surgery arthrogenic muscle inhibition - Establish segmental coordination and patterning i.e.- lumbo-pelvic control and hip dominant movement strategies - Establish multidirectional proprioception and joint stability in weight bearing - Increase muscle fiber size and density through hypertrophic programing and progressive loading for major muscle groups of lower limb i.e. Glutes, quadriceps, hamstrings, calf
Treatment Guidelines	**Pain/Swelling/ROM** - Maintenance of a calm quiet knee joint **1. <u>Primary Aim:</u>** **Hypertrophy** - Quadriceps/ extension exercises: IRQ and SLR with resistance, blood flow restriction therapy - Co-contraction exercises are more effective in reducing anterior tibial translation than low load knee extension exercises (Yanagawa et al., 2002). Quickly progress from unweighted quadriceps exercises to: - Closed chain exercises as tolerated - Squats focusing on hip dominant strategy - Wall sits, leg press, assisted single leg squats increasing knee flexion ranges as tolerated. Hamstrings - Open/close chain exercises as tolerated. - Double leg/Unilateral long lever hamstring bridges - Unilateral prone lying hamstring curls (+/- resistance) to failure Glutes

	- Open/ Closed chain exercises as tolerated - Ensure appropriate lumbo-pelvic control throughout Calf - Closed chain double leg calf raises, progressing to single leg and to weighted as tolerated **Blood flow restriction resistance training (BFR-RT)** - This can improve skeletal muscle hypertrophy and strength to a similar extent to heavy load resistance training with a greater reduction in knee joint pain and effusion, leading to greater overall improvements in physical function (Hughes et al., 2017) **Maximum Strength** - Double leg exercises to progress to single leg as tolerated - Pain & Swelling Free - Compound lifts - 5 repetition maximum (5 RM) targets: - Hip thrust (1 – 1.5% BW) - Deadlift (1 – 1.5% BW) - Front Squat (1 – 1.5% BW) - Single leg assisted squat (0.25%BW) - Failure at 5 – 6 repetitions for all max strength exercises **<u>2. Secondary Aims:</u>** **Balance, proprioception and joint stability** - Single leg stance (flat, unstable surface, addition of perturbation) - Single leg squat to box - High knee walking- focusing on achieving terminal knee extension **Upper limb** - Maintenance of upper limb strength/muscle mass using isolated upper limb exercises as appropriate **Cardio** - UBE, water walking, swimming, stair master, ski machine, elliptical machine, walking, *Stationary bike as per consultant*
Progression Criteria	- Maintain terminal knee extension (including hyperextension) and achieve full knee flexion - Competent in performing a bodyweight squat, pain free with the appropriate hip strategy, and minimal knee valgus - Progress from activation/hypertrophy to strength when asymmetries < 20%, and pain and swelling are controlled

Phase II (8-16 weeks) Power and Reactive Strength
Alongside restoration of limb muscle size and strength symmetry, symmetrical reactive strength (<10% deficit) must be achieved during the rehabilitative process. Reactive strength and the ability to pre-activate lower limb muscle groups is imperative in the prevention of recurrent ACL rupture, as ACL rupture has been estimated to occur within 17 - 50 ms of initial ground contact (Krosshaug et. al 2007). Early reactive strength drills can be introduced in parallel with hypertrophy and strength training, provided the reconstructed knee is non-reactive during and post sessions. The introduction of landing drills is also discussed in this phase. During landing a small knee flexion angle and large posterior ground reaction force, can increase ACL loading, we must integrate re-

learning of landing mechanics which minimise anterior shear, valgus, varus and internal rotation moments throughout the rehabilitation process.	
Goals	- Remain pain free with minimal swelling - Increase muscle fibre recruitment & size - Improve neuromuscular control during double and single leg dynamic activities - Improve ability to coordinate multiple joints with stiffness - Improve explosive strength - Maintain Full ROM - Quadriceps strength > 200% bodyweight & < 20 % asymmetry between quadriceps, measured via isokinetic dynamometry
Treatment Guidelines	**Hypertrophy and Max strength** - Continue hypertrophic training as detailed in phase 1 (b) as appropriate - Maintain muscle mass through maximum strength training and inclusion of hypertrophic repetition ranges (8 - 12 reps), or sets to failure - Progress from activation/hypertrophy to strength when asymmetries < 20%, and pain and swelling are controlled, and full ROM is achieved - May begin open chain concentric quad exercises at 10-12 weeks: Knee extension machine **Reactive/Explosive Strength** - Introduce low level reactive/explosive when able to perform a pain free body weight squat with appropriate strategies **Introductory Reactive strength Drills** - Double leg □ Single leg drop squats - Double leg □ Single leg countermovement jumps (CMJ) - Double leg □ Single leg box Jumps, gradually increasing height as tolerated - Double leg □ Single leg landing from box, gradually increasing height as tolerated. Cue for: - Hip dominant strategy - Minimal knee valgus - Fast landings **Advanced Reactive Strength Drills:** - Multi-directional reactive strengthening drills i.e.- multidirectional cone/hurdle hops. Cue for: - Short ground contact time - Jump height - Minimal knee valgus - Minimal ipsilateral trunk sway **Plyometric Activities:** - Skipping - Double leg to Single leg hops Cue for: - Short ground contact time - Jump Height **Power** - Continuing aforementioned compound exercises with the ***intent*** to complete the lifts at maximal speed. **Proprioception/Neuromuscular Control** - Progression of balance training - Single leg tasks, Dual Tasking, Addition of unstable surfaces

	- Multi-directional joint stability
Progression Criteria to Phase 3 Linear Running	- No pain or swelling. Load to be reduced if increase in same - Avoid overloading patella tendon with plyometric exercises **ACL lab 1 testing (4-6 months, Sports Surgery Clinic):** ● Isokinetic dynamometry ● Force plate counter movement jump (CMJ) assessment ● Force plate drop jump assessment ● 3D running technique analysis ● Assessment of neuromuscular control **Max Strength (as per Isokinetic Dynamometry*)** >260% BW (Male), >250% BW (Female) Quadriceps >170% BW (Male), > 160% BW (Female) Hamstrings <20% Asymmetry in Quadriceps and Hamstring strength Hamstring strength 65% that of quadriceps strength *figures detailed are end-stage rehabilitation goals. Review aims to highlight persisting deficits/areas requiring further development **Control:** Satisfactory Knee and trunk control during functional movement testing, with appropriate hip dominant movement strategies where indicated. **Reactive Strength (As interpreted via Force Plate analysis):** < 20% limb asymmetry

Phase III (16 + weeks) Linear Running	
Return to running should be objective, based on the presentation of the knee and athlete, as should progression beyond running and return to sport. (Wilk and Arrigo, 2017). *On 4-6 month review, quadriceps and hamstring strength with be measured objectively via isokinetic dynamometry. At this stage of the rehabilitative process, the athlete can often achieve satisfactory strength score. Limb symmetry is of particular interest, as is the quadriceps to hamstring strength ratio, as a large quadriceps anterior shear force exerted on the proximal tibia, if not balanced by hamstrings force production, becomes a risk factor for non-contact ACL injury.* *It is vital that strength and hypertrophy training be continued and maintained throughout the rehabilitative process, as we often see a decrease in strength scores from 6 month to 9 month reviews as an athletes focus may shift more towards sports specific rehabilitation.*	
Goals	- Remain pain and swelling free - Continue to improve strength - Improve running economy - Improved load absorption - Reduced ground contact time - Maintain segmental Stiffness
Treatment Guidelines	**Continue & maintain maximum strength, muscle size, reactive strength, neuromuscular control as detailed previously.** **Load monitoring** Avoid anterior knee pain/patellar tendinopathy flare ups (Arundale et al. 2018) **Deceleration/Lateral Agility drills**

	- Lateral hops - Single leg broad jumps - Education & cueing re. avoidance of knee valgus on landing, hip drop, and ipsilateral trunk lean **Running volume** - **2 x run per week** - Gradual increase in volume/intensity, not exceeding >10% increase in load weekly - Load to be reduced if pain/swelling during or post session **Linear running drills** - Gradual increase in volume/intensity, not exceeding >10% increase in load weekly - Load to be reduced if pain/swelling during or post session **Linear running drills** - Cue for knee drive, short ground contact times, segmental stiffness, hip lock o Drill for improvement in same as required
Progression Criteria to Phase IV Multi-Direction	**Max strength:** < 10% asymmetry in quadriceps and hamstring strength **Eccentric Strength (Deceleration)** <15% asymmetry in countermovement jump eccentric impulse, as measured via forceplates assessment **Lateral Hop Drills:** No knee valgus, hip drop, or ipsilateral trunk lean on landing **Running:** Pain Free, Swelling Free Exposure and volume of linear running completed which replicates the specific demands of the athlete's sport Satisfactory running technique on analysis ● Short ground contact times with ability to produce vertical force ● Appropriate knee drive ● Hip Lock (neutral pelvis)

Phase IV (16- 24 weeks) Multi-Directional	
Unplanned sidestepping, or change of direction, closely mimics game like scenarios in multidirectional field sports. An unplanned change of direction versus a planned change of direction produces a scenario more similar to that of match play through decreased decision time, increased knee loading and challenging the integrity of soft tissue structures in the knee (Brown et al. 2014). It is therefore important that unplanned change of direction is rehabilitated, with an aim to achieving a satisfactory base position (hip dominant pattern with knee flexion, without genu valgum or trunk lean, with the planted foot facing in the direction of acceleration).	
Goals	- Satisfactory Base Position - Develop lateral power/rate of force development - Develop Lateral Stiffness - Achieve Change of Direction (COD) position without genu valgum, hip drop or trunk lean, and with good foot positioning - Gradual increase in workload avoiding rapid spikes (10% increase per week)

Treatment Guidelines	Maintain strength/muscle size/reactive strength/linear running as detailed above or progress if still indicated. **COD Mechanics Drills** To incorporate as part of gym sessions Ensure competency in completing the various change of direction techniques - Cross-over step - Lateral shuffle Cue for - Hip dominant pattern - Neutral foot positioning - Forward trunk lean - Staying low (low Centre of Mass) **Cutting Drills** Progress through the cutting techniques - Pre-planned cutting e.g- slalom cutting 45 degrees cuts - Unplanned or Random cutting - Jump stop and cut - Progress through by decreasing the angle of cuts.
Progression Criteria to Phase	**ACL lab 1 testing (4-6 months, Sports Surgery Clinic):** ● Isokinetic dynamometry ● Force plate counter movement jump (CMJ) assessment ● Force plate drop jump assessment ● 3D running technique analysis ● Assessment of neuromuscular control **Max Strength (as per Isokinetic Dynamometry*)** >260% BW (Male), >250% BW (Female) Quadriceps >170% BW (Male), > 160% BW (Female) Hamstrings <10% Asymmetry in knee flexor and knee extensor strength Hamstring/Quadriceps strength ratio > 65% *figures detailed are end-stage rehabilitation goals. Review aims to highlight persisting deficits/areas requiring further development **Control:** Satisfactory Knee and trunk control during functional movement testing, with appropriate hip dominant movement strategies where indicated. **Reactive Strength (As interpreted via Force Plate analysis):** < 20% limb asymmetry

Phase V (24-36+ weeks) Sports Specificity and Conditioning
It is vital that strength and hypertrophy training be continued and maintained throughout the rehabilitative process, as we often see a decrease in strength scores from ACL Lab 1 and ACL Lab 2 reviews as an athletes focus may shift more towards sports specific rehabilitation. *While no gold standard currently exists for evaluating return to play readiness following ACLR, Dingenen and Gokeler (2017) suggest a biopsychosocial approach to return to day decision making, as a replacement to the traditional time based and knee focused approach. Using this approach, the repeated athletic evaluations carried out during the rehabilitative process (3, 6 and 9 month testing) allow a multi segmental evaluation, which should be supported by a shared decision making approach. Decision modifiers which may influence the return to play decision include timing of the season, external pressures (coaches/parents/financial), lifestyle changes, individual goals*

and athlete priorities. These should be considered in line with objective data to ensure the athlete's return to play is optimally timed to minimise risk of re-injury.	
Goals	- Maximum, explosive and reactive strength asymmetry <10% - Achieve/maintain maximal strength and endurance - Maintain normalised neuromuscular control - Aerobic Conditioning - Speed endurance - Skill re-integration - Open skill drills - Training re-integration - Assess tolerance of sport-specific training (no pain/swelling/stiffness) - Exposure to sport specific fatigue - Return to performance/full, unrestricted sports
Treatment Guidelines	**Strength Training** - Continue and progress - Develop programming suited to the athlete's training schedule to facilitate long term continuation and maintenance **Neuromuscular Training** - Continue and progress, integrate into pre-training warm ups **Running** - Continue and progress Linear Running load and intensity tolerance - Integrate COD drills into pre-training warm ups *Environmental factors such as task uncertainty, decision making, open vs closed environments* **Sports Specific Programming** - Running/cutting/agility drills - Progressive re-integration into team training as tolerated e.g. o Tolerate warm-up o Tolerate non-contact running/fitness drills o Tolerate non-contact skills drills o Tolerate contact skills drills o Tolerate training game play o Gradual re-integration into competitive game play
Progression Criteria to Phase	**ACL Lab 2 Testing 7-9 months (Sports Surgery Clinic)** ● 3D testing of jumping, landing and cutting ● Isokinetic Strength Test ● Force plate hop testing **Hop Tests:** Limb symmetry index > 90% **Max Strength (as per Isokinetic Dynamometry):** >260% (Male), >250% (Female) Bodyweight Quads >170% (Male), >160% (Female) Bodyweight Hamstrings > 90% limb symmetry index on knee extensor and knee flexor strength **Hamstrings/Quadriceps strength ratio:** > 65% Successful gradual reintroduction to game play completed as detailed above **The athlete should demonstrate knowledge of:** - Continued rehabilitation and how to incorporate same into training schedule when fully returned to play - High risk positions and how to minimise exposure to same - Appropriate, safe change of direction technique

Reference List

Arundale AJH, Capin JJ, Zarzycki R, Smith A, Snyder-Mackler L. Functional and Patient-Reported Outcomes Improve Over the Course of Rehabilitation: A Secondary Analysis of the ACL-SPORTS Trial. Sports Health. 2018 Sep/Oct;10(5):441-452.

Brown, S.R., Brughelli, M., Hume, P.A., (2014), "Knee Mechanics During Planned and Unplanned Sidestepping: A Systematic Review and Meta-analysis," *Sports Medicine*, 44, pp. 1573 - 1588. doi: 10.1007/s40279-014-0225-3

Claes, S., Verdonk, P., Forsyth, R., Bellemans, J., (2011), "The ''Ligamentization'' Process in Anterior Cruciate Ligament Reconstruction. What Happens to the Human Graft? A Systematic Review of the Literature." *The American Journal of Sports Medicine*, 39 (11), doi: 10.1177/0363546511402662

Dingenen, B., and Gokeler, A., (2017), "Optimization of the Return-to-Sport Paradigm After Anterior Cruciate Ligament Reconstruction: A Critical Step Back to Move Forward," *Sports Medicine*, 47 (8), pp 1487–1500

Grindem, H., Granan, L.P., Risberg, M.A., Engebretsen, L., Snyder-Mackler, L., and Eitzen, I., (2015), "How does a combined pre-operative and post-operative rehabilitation program influence the outcome of ACL reconstruction 2 years after surgery? A comparison between patients in the Delaware-Oslo ACL Cohort and the Norwegian Knee Ligament Registry," *British Journal of Sports Medicine*, 49 (6), pp. 385 - 389. doi: 10.1136/bjsports-2014-093891

Hauger A, Reiman M, Bjordal J, Sheets C, Ledbetter L, Goode A. Neuromuscular electrical stimulation is effective in strengthening the quadriceps muscle after anterior cruciate ligament surgery. Knee Surgery, Sports Traumatology, Arthroscopy. 2017;26(2):399-410.

Hughes, L., Paton, B., Rosenblatt, B., Gissane, C. and Patterson, S., 2017. Blood flow restriction training in clinical musculoskeletal rehabilitation: a systematic review and meta-analysis. British Journal of Sports Medicine, 51(13), pp.1003-1011.

Krosshaug, T., Nakamae, A., Boden, B.P., Engebretsen, L., Smith, G., Slauterbeck. J.R., Hewett, T.E., and Bahr, R., (2007) "Mechanisms of anterior cruciate ligament injury in basketball: video analysis of 39 cases," *The American Journal of Sports Medicine*, 35 (3), pp. 359 - 367. doi: https://doi.org/10.1177/0363546506293899

Van Grinsven S, van Cingel RE, Holla CJ, van Loon CJ. Evidence-based rehabilitation following anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2010 Aug;18(8):1128-44.

Wilk, K.E., Arrigo, C.A., (2017), "Rehabilitation Principles of the Anterior Cruciate Ligament Reconstructed Knee Twelve Steps for Successful Progression and Return to Play," *Clinical Sports Medicine*, 36, pp. 189 - 232. doi: http://dx.doi.org/10.1016/j.csm.2016.08.012

Yanagawa, T., Shelburne, K., Serpas, F. and Pandy, M., 2002. Effect of hamstrings muscle action on stability of the ACL-deficient knee in isokinetic extension exercise. Clinical Biomechanics, 17(9-10), pp.705-712.