AUTOLOGOUS CHONDROCYTE IMPLANTATION (ACI) CLINICAL PRACTICE GUIDELINE

Background

Autologous chondrocyte implantation (third generation) is a two stage surgical procedure indicated for medium to large (≥2 cm^2) symptomatic full thickness chondral lesions. Stage one is performed arthroscopically, where a small sample of healthy cartilage is harvested from a non-weight bearing area of the knee. The chondrocyte sample is sent to a laboratory where the cells are cultivated on a scaffold for 4-6 weeks. Stage two is performed through an open procedure, or arthrotomy. The cartilage defect is exposed and debrided to an area with vertical margins. The scaffold implant is placed in the defect and secured fibrin sealant. These third generation ACI techniques eliminate the suture fixation previously required with second-generation ACI procedures. The various implantation procedures are as follows:

- Matrix-Induced Autologous Chondrocyte Implantation (MACI)- thin scaffold seeded with chondrocytes
- NeoCart- chondrocytes growing and producing extracellular matrix throughout scaffold
- NovoCart- full thickness scaffold seeded with chondrocytes

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

Expectations	• PT and CPM should begin at post-op day 7-10 days • Return to sport: 12-15 months • Please review operative report as lesion size and location may dictate speed of progression	
Risk Factors	• CI requires extensive rehabilitation and can often exhaust insurance approved PT visits. Consider decreasing initial visit frequency, use of home NMES unit and daily self-ROM. Long-term quadriceps strength deficits typically present >1 year post-operatively.	

Concomitant Procedures	• Do not change protocol based on multiple defects, meniscus repair or ligamentous reconstruction
	  • If multiple defects include a patellofemoral lesion, following the patellofemoral precautions
	• TTO Adjustments:
	  • Open brace to 0-35° at weeks 5-6
	All CKC interventions performed through protected ROM (90-45°) before transition to full ROM	

Weight Bearing Progression	**Tibiofemoral (No Brace)** • Phase 1 *(week 1):* NWBing • Phase 2 *(week 2-3):* 25% BW (weeks 1-2) to 50% BW (week 3) • Phase 3 *(weeks 4-5):* 60% BW (week 4) to 80% BW (week 5) • Phase 4 *(weeks 6-7):* 90% to100% BW • Phase 5 *(weeks 8-10):* Full BW with normal gait pattern	**Patellofemoral (TROM Extension Brace)** • Phase 1-3 *(weeks 1-5):* Full BW, brace locked in full extension ○ Open brace at week 5-6 • Phase 4 *(weeks 6-7):* Discharge brace • Phase 5 *(weeks 8-10):* Normal gait without brace
Range of Motion Progression	• Phase 1/2 *(weeks 1-3):* 0-45° (week 2) to 0-90° (week 3) • Phase 3 *(weeks 4-5):* 0-105° (week 4) to 0-120° (week 5) • Phase 4 *(weeks 6-7):* 0-125° (week 6) to 0-135° (week 7) • Phase 5 *(weeks 8-10):* Full AROM • **Same ROM progression for tibiofemoral and patellofemoral lesions**	

Functional Testing	• Isometric testing: 4-5 months (at 90 degrees)
	• Isokinetic testing: 6, 9, 12 months and discharge
	• Hop testing (Appropriate after 80% symmetry achieved on isokinetic testing)
	  ○ SL hop for distance
	  ○ Triple hop
	  ○ Cross over hop
	  ○ Timed 6m hop
	Functional strength testing and hop testing should be reserved for patients returning to high-level activity	

Patient Reported Outcomes	Collect at least one of the following at initial evaluation, every 6 weeks and discharge. Be consistent with which outcome tool is collected. • Knee Injury and Osteoarthritis Outcome Score (KOOS) • International Knee Documentation Committee (IKDC)	
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 **Tibiofemoral lesions: PWBing for 6-8 weeks. See above WBing progression**	

Criteria to Initiate Running and Jumping	1. ROM: full, pain-free knee ROM, symmetrical with the uninvolved limb 2. Strength: Isokinetic testing 80% or greater for hamstring and quad at 60º/sec and 300º/sec 3. Effusion: 1+ or less 4. Weight Bearing: normalized gait and jogging mechanics 5. Neuromuscular Control: Pain-free hopping in place
Criteria for Return to Sport	1. ROM: full, painfree knee ROM, symmetrical with the uninvolved limb 2. Strength: Isokinetic testing 90% or greater for hamstring and quad at 60º/sec and 300º/sec 3. Effusion: No reactive effusion ≥ 1+ with sport-specific activity 4. Weight Bearing: normalized gait and jogging mechanics 5. Neuromuscular control: appropriate mechanics and force attenuation strategies with high level agility, plyometrics, and high impact movements 6. Functional Hop Testing: LSI 90% or greater for all tests 7. Physician Clearance

Chondrocyte Rehabilitation Maturation Phases

Phases of post-operative rehabilitation and the associated graft maturation timeline

Rehabilitation Phase	Stage of Repair Tissue
Phase 1: weeks 0-1	Implantation and protection (0-6 weeks)
Phase 2: weeks 2-3	
Phase 3: weeks 4-6	
Phase 4: weeks 7-12	Transition and proliferation (6-12 weeks)
Phase 5: months 3-6	Remodeling (12-26 weeks)
Phase 6: months 6-9	
Phase 7: months 9-RTS	Maturation (26 weeks onward) ***The graft will continue to remodel for up to 1 year post-op****

Red/Yellow Flags

Red Flags ***(signs/symptoms that require immediate referral for re-evaluation)***	• Signs of DVT *(Refer directly to ED)*
	  • Localized tenderness along the distribution of deep venous system
	  • Entire LE swelling
	  • Calf swelling >3cm compared to asymptomatic limb
	  • Pitting edema
	  • Collateral superficial veins
	• Mechanical block or clunk *(Refer to surgeon for re-evaluation)*
	• Lack of full knee extension by 4-6 weeks *(Refer to surgeon for re-evaluation)*

Yellow Flags ***(signs/symptoms that require modification to plan of care)***	• Persistent reactive pain or effusion following therapy or ADLs • *Decrease intensity of therapy interventions, continue effusion management and provide patient education regarding activity modification until reactive symptoms resolve*

Phase I: Weeks 0-1

Patients will not begin physical therapy until post-operative days 7-10. Phase 1 will be completed independently through a home exercise program provided on the day of surgery. Formal physical therapy will begin in Phase 2.

Goal	Maintain joint mobility and muscle tone while adhering to all post-operative precautions
Range of Motion	• 0-45° • CPM to start at day 7-10
Weight Bearing	Tibiofemoral: ≤20% BW Patellofemoral: Full BW, brace locked in full extension
Suggested Interventions	• Ankle pumps • Quadriceps, hamstring and gluteal isometrics • Diaphragmatic breathing • Effusion management strategies, including RICE

Phase II: Weeks 2-3

Goals	The patient should achieve pain-free and full passive knee extension. Focus is placed on maintaining muscle tone, ensuring proper wound healing and effusion management.

Range of Motion	**0-90° (***Goal: early AROM though safe range)*
	• *Flexion achieved though CPM and AAROM (heel slides, wall slides, AAROM row machine)*
	  ○ *Total volume: 300+ repetitions/day*
	• *Extension achieved through bag hangs (Appendix A), prone hangs, heel prop towel stretch*
	  ○ *Total volume: 60 min/day*

Weight Bearing	Tibiofemoral**:** 30% to 50% BW Patellofemoral: Full BW, brace locked in full extension

Suggested Interventions	• Ankle pumps
	• Quadriceps, hamstring and gluteal isometrics
	• Prone TKE
	• SLR-4 way
	• Patellar mobilization in all directions
	• Gait training
	• Recumbent cycling- for ROM only (week 3)
	• SAQ (no resistance)
	• LAQ (no resistance, through protected ROM (90-45 degrees)
	• Continue CPM, effusion management and NMES in long sitting
	For PF lesions only: *(Must be performed in locked knee brace)*
	  ○ Weight shifting
	  ○ DL heel raise
	  ○ SL balance
	• NMES in long sitting

Blood Flow Restriction Training *Appendix D*	• 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). *BFR should never be performed during a plyometric exercise.* • 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 (in long sitting)	• NMES pads are placed on the proximal and distal quadriceps • Patient: Seated in long sitting (knees extended) • The patient is instructed to relax while the e-stim generates at least 50% of their max volitional quadriceps contraction OR maximal tolerable amperage without knee joint pain • 10-20 seconds on/ 50 seconds off x 15 min
Criteria to Progress to Phase 3	By the end of week 3: • Pain-free knee flexion of 90° • Pain-free and full passive knee extension • Proficient heel-to-toe gait with 50% BW for tibiofemoral grafts or full BW for patellofemoral grafts • Reduced and well-controlled post-operative pain and edema • Ability to perform a strong isometric quadriceps contraction (full tetany and superior patellar glide) • Proficiency with home-exercise program

Phase III: Weeks 4-6

Goals	Emphasis is placed on increasing knee flexion ROM and improving quadriceps, gluteal and core strength

Range of Motion	**0-105° (week 4) to 0-125° (week 6)**
	• *Flexion achieved though CPM and AAROM (heel slides, wall slides, AAROM row machine)*
	  ○ *Total volume: 300+ repetitions/day*
	• *Extension achieved through bag hangs (Appendix A), prone hangs, heel prop towel stretch*
	  ○ *Total volume: 60 min/day*

Weight Bearing	Tibiofemoral**:** 60% BW (week 4) to 80% BW (week 5) Patellofemoral: Full BW, open brace at weeks 5-6

Suggested Interventions	• Continue Phase 1 and 2 interventions
	• SLR-Flexion progressions
	  ○ Semi-reclined or seated
	  ○ Add ER
	  ○ Perform with eyes closed (cortical training)
	  ○ Speed
	  ○ Isometric holds at end-range
	• Heel slides
	• Clamshells
	• Seated or standing hip ab/adduction (depending on WBing status)
	• Trunk stability interventions
	  ○ TrA isometric progression
	  ○ Prone/side planks
	• Upright cycling (weeks 5-6)
	• Standing TKE (weeks 6-8)
	• Partial BW Shuttle Press (week 6-8)
	• OKC Hamstring strengthening (week 6-7)
	• Progress NMES to seated with tibia fixed at 60° of knee flexion
	• Discharge CPM at 6 weeks
	• BFR (continue as in early phase, adding appropriate exercises)
	• Continue effusion management strategies

NMES Parameters (with tibia fixed at 60° of knee flexion) *Appendix B*	• NMES pads are placed on the proximal and distal quadriceps • Patient: Seated with the knee in at least 60º 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 Progress to Phase 4	By the end of week 6: • Pain-free active knee flexion to 125° • Pain-free gait with 80% BW for tibiofemoral grafts or full BW for patellofemoral grafts • 3x10 SLR without quadriceps lag • Proficiency with home exercise program

Phase IV: Weeks 7-12

Goals	The patient works toward movement independent of ambulation devices and knee braces. Full ROM should be achieved and balance/proprioception interventions are initiated.
Range of Motion	0-125° (week 6), 0-135° (week 7) to full ROM (week 8-10)
Weight Bearing	Tibiofemoral**:** 90% BW (week 6), 100% BW (week 7) to full WBing without obvious gait deviation (week 10) Patellofemoral: Discharge brace
Suggested Interventions	• Continue Phase 2 and 3 interventions • Continue ROM interventions until symmetrical ROM is achieved • Partial BW Shuttle Press (week 6-8) • OKC Hamstring strengthening (week 6-7) • Multi-angle isometrics • Balance and proprioception interventions • Mini squats: 0-45 degrees (week 8-10) • Heel Taps: 2-4" (weeks 10-12) • Step Ups: 6-8" (weeks 10-12) • Resisted OKC quadriceps strengthening through 90-45° protected ROM (week 10-12) • BFR (continue as in early phase, adding appropriate exercises) • Continue NMES (seated with tibia fixed at 60° of knee flexion) • Continue effusion management strategies as needed
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) Weight Bearing: Demonstrates pain-free ambulation without visible gait deviation
Criteria to Progress to Phase 5	By week 12: • Pain-free active ROM • Pain-free upright cycle ergometry • Pain-free ambulation without visible gait deviation • Proficiency in home exercise program

Phase V: Months 3-6

Goals	The majority of patients return to work either on a part-time or full-time basis. Patients should continue skilled physical therapy to progress functional, CKC strengthening.
Range of Motion	Full AROM
Weight Bearing	Full WBing, normal gait without brace
Suggested Interventions	• Continue Phase 3 and 4 interventions • Bridging • Standing SL calf raises • Resisted OKC quadriceps strengthening through full ROM (week 12-14) • Lunges • SL sit to stand, through protected ROM • Elliptical • Outdoor cycling if desired (months 5-6) • Rowing ergometry as tolerated (months 5-6) • Continue NMES until 80% symmetry is obtained • Continue effusion management as needed
Isometric Testing	Isometric testing is appropriate at 4-4.5 months
Criteria to Progress to Phase 6	By 6 months: • Ability to negotiate stairs and mild gradients without pain or reactive effusion • Return to work, depending on the demands of the job • Ability to perform 3x10 heel raise on 6” step with neutral frontal and sagittal plane alignment • Proficiency in home exercise program

Phase VI: Months 6-9

Goals	Patient progress OKC interventions. Strength testing is performed to determine readiness to initiate light plyometrics and walk-jog progression.
Range of Motion	Full AROM
Weight Bearing	Full WBing, normal gait without brace

Suggested Interventions	• Continue phase 3-5 interventions
	• Progress and increased difficulty of OKC exercises
	• Continue to progress SL eccentric strengthening through body weight and machine interventions
	• Once strength criteria have been met, perform the following progression:
	  ○ PBW jumping on the shuttle (DL ➔ SL)
	  ○ Full body weight jumping progression
	• Walk-jog program

Isokinetic Testing *Appendix E, F*	Isokinetic testing is appropriate at 6 and 9 months **Functional strength testing should be reserved for patients returning high-level activity**
Criteria to Initiate Running and Jumping	1. ROM: full, pain-free knee ROM, symmetrical with the uninvolved limb 2. Strength: Isokinetic testing 80% or greater for hamstring and quad at 60º/sec and 300º/sec 3. Effusion: 1+ or less 4. Weight Bearing: normalized gait and jogging mechanics 5. Neuromuscular Control: Pain-free hopping in place
Criteria to Progress to Phase 7	By 9 months: • Quadriceps and hamstring symmetry of 80% or greater • Ability to tolerate walking distances of 3 miles or greater without reactive pain or effusion • Ability to effectively negotiate uneven ground, including soft sand, without reactive pain or effusion • Ability to return to pre-operative low-impact recreational activities, including cycling, elliptical and weight training

Phase VII: Months 9-Return to Sport

Goals	The patient is able to resume all normal functionality and will continue to progress towards return to sport.
Range of Motion	Full AROM
Weight Bearing	Full WBing, normal gait without brace
Suggested Interventions	• Continue phase 3-6 interventions • Step-hold progression to SL hop progression • Sports-specific training • Agility • Plyometrics
Isokinetic Testing *Appendix E, F, G*	Isokinetic testing is appropriate at 12 months and discharge **Functional strength testing and hop testing should be reserved for patients returning high-level activity**
Criteria to Return to Sport	1. ROM: full, painfree knee ROM, symmetrical with the uninvolved limb 2. Strength: Isokinetic testing 90% or greater for hamstring and quad at 60º/sec and 300º/sec 3. Effusion: No reactive effusion ≥ 1+ with sport-specific activity 4. Weight Bearing: normalized gait and jogging mechanics 5. Neuromuscular control: appropriate mechanics and force attenuation strategies with high level agility, plyometrics, and high impact movements 6. Functional Hop Testing: LSI 90% or greater for all tests 7. Physician Clearance
	Activities that generate high compression, shear and rotational loads are to be avoided until 12-18 months, or as directed by orthopaedic surgeon ***Full RTS expected between 12-15 months post-operatively***

Appendix A: Bag Hang

Emphasis on low load, long duration stretching

- *Goal: 60 minutes of bag hang time total per day.*
- *Ideally: 4x15 minutes (or greater) per day*

Appendix B: NMES Set Up

2 or 4 pad set-up is appropriate

- NMES pads are placed on the proximal and distal quadriceps
- Patient: Seated with the knee in at least 60º 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

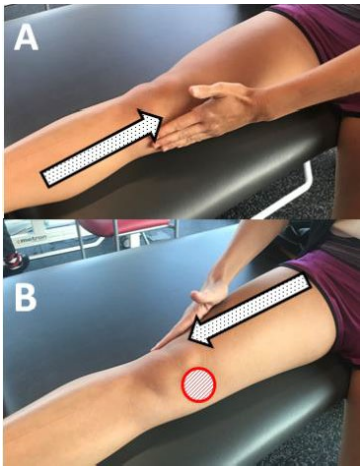
Appendix C: Stoke Test / Swelling Assessment

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



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+

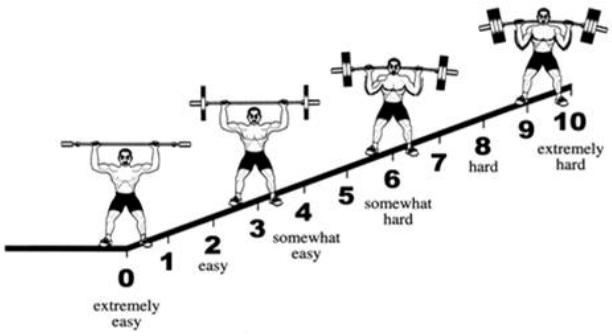
Indications for Activity

3+ or 2+	1+	Trace or Zero
Red Light	**Yellow Light**	**Green Light**
• 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)	• 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)	• May participate in running, jumping and normal lifting routine without restriction • Continue to monitor swelling after activity

Appendix D: Blood Flow Restriction Training

Precautions (must get permission from MD)	Contraindications
▪ 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	▪ 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

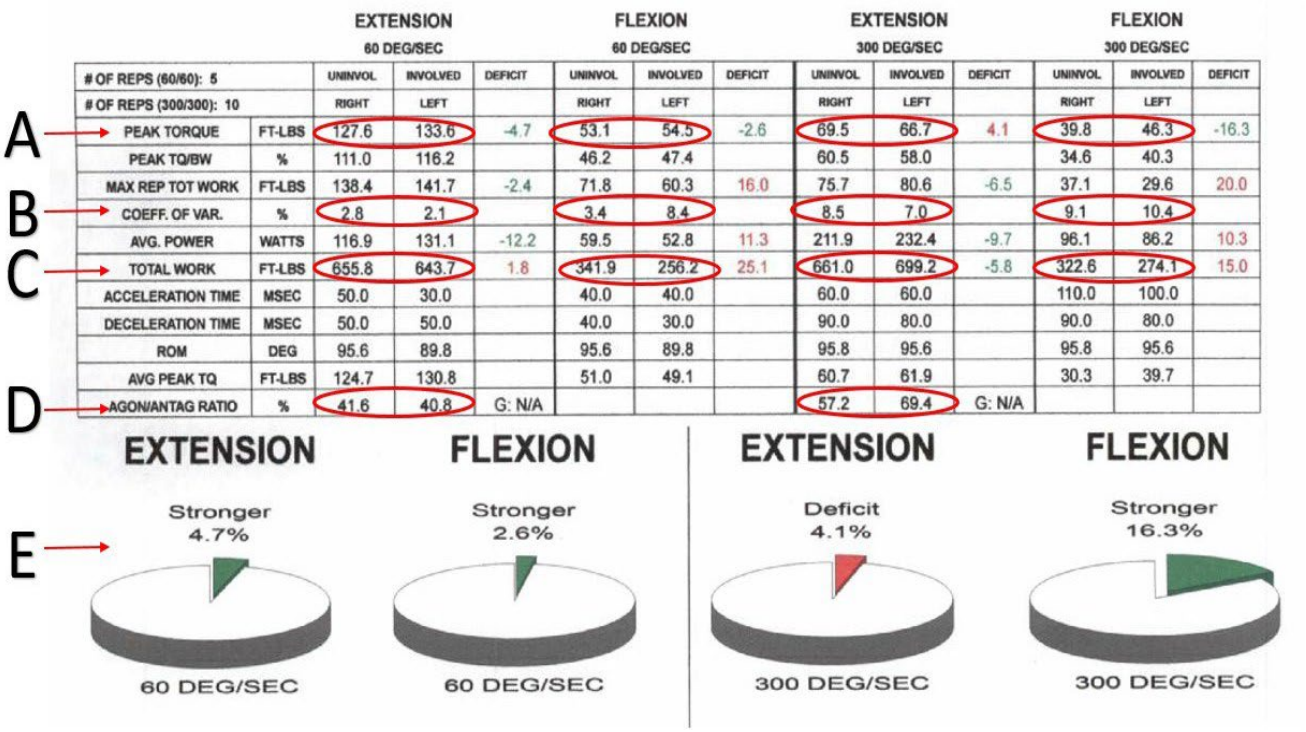
Training Intensity: 20-40% 1RM or use the Omnibus Resistance Exercise Scale (below). Patient chooses weight/resistance that corresponds to 2-3



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



	EXTENSION 60 DEG/SEC			FLEXION 60 DEG/SEC			EXTENSION 300 DEG/SEC			FLEXION 300 DEG/SEC		
# OF REPS (60/60): 5	UNINVOL.	INVOLVED	DEFICIT	UNINVOL.	INVOLVED	DEFICIT	UNINVOL.	INVOLVED	DEFICIT	UNINVOL.	INVOLVED	DEFICIT
# OF REPS (300/300): 10	RIGHT	LEFT		RIGHT	LEFT		RIGHT	LEFT		RIGHT	LEFT	
A → PEAK TORQUE FT-LBS	127.6	133.6	-4.7	53.1	54.5	-2.6	69.5	66.7	4.1	39.8	46.3	-16.3
PEAK TQ/BW %	111.0	116.2		46.2	47.4		60.5	58.0		34.6	40.3	
MAX REP TOT WORK FT-LBS	138.4	141.7	-2.4	71.8	60.3	16.0	75.7	80.6	-6.5	37.1	29.6	20.0
B → COEFF. OF VAR. %	2.8	2.1		3.4	8.4		8.5	7.0		9.1	10.4	
AVG. POWER WATTS	116.9	131.1	-12.2	59.5	52.8	11.3	211.9	232.4	-9.7	96.1	86.2	10.3
C → TOTAL WORK FT-LBS	655.8	643.7	1.8	341.9	256.2	25.1	661.0	699.2	-5.8	322.6	274.1	15.0
ACCELERATION TIME MSEC	50.0	30.0		40.0	40.0		60.0	60.0		110.0	100.0	
DECELERATION TIME MSEC	50.0	50.0		40.0	30.0		90.0	80.0		90.0	80.0	
ROM DEG	95.6	89.8		95.6	89.8		95.8	95.6		95.8	95.6	
AVG PEAK TQ FT-LBS	124.7	130.8		51.0	49.1		60.7	61.9		30.3	39.7	
D → AGON/ANTAG RATIO %	41.6	40.8	G: N/A				57.2	69.4	G: N/A			

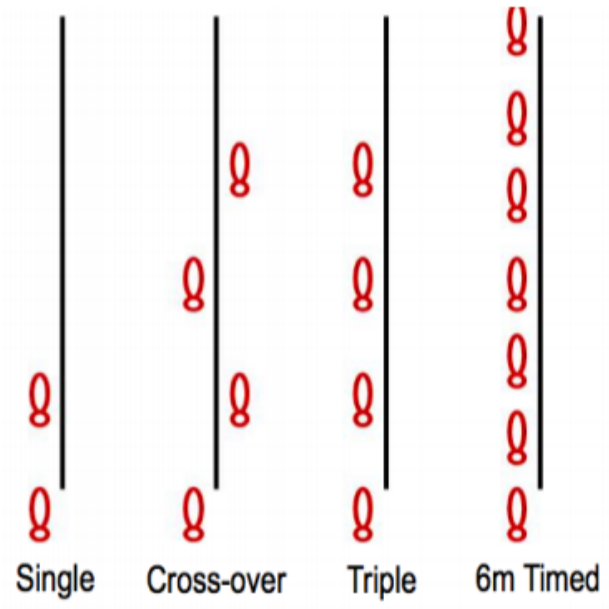
		Definition	Clinical Impact	What to do
A	Peak Torque (ft-lbs)	Peak torque during repetitions	Symmetry criteria (see 'E'- this is the data represented in pie charts)	If <80%; continue unilateral, high resistance strength training
B	Coefficient of Variance (%)	Between repetition variability	Goal: < 15%	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

Isokinetic Dynamometry		• Considered the “gold standard” • 60°/sec for strength and power assessment • 300°/second for speed and endurance assessment
Hand Held Dynamometry with Static Fixation at 90°		• Appropriate alternative • Results may overestimate quadriceps strength symmetry: be cautious with data interpretation
SL 1RM Knee Extension Machine: 90°- 45°		• 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
SL 1RM Leg Press		• Fair alternative • Results in significant overestimation of quadriceps strength symmetry due to compensation from other LE muscle groups
SL 1RM Knee Extension Machine: 90°- 0°		• 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%.



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