

# AUTOLOGOUS CHONDROCYTE IMPLANTATION (ACI) CLINICAL PRACTICE GUIDELINE

## Disclaimer

- Progression is time and criterion-based, depending on soft tissue healing, patient demographics, and clinician evaluation.
- For questions, contact Dr. Sujan Gogu's clinic.

## Background

### Autologous Chondrocyte Implantation (ACI)

A two-stage surgical procedure for medium to large symptomatic full-thickness chondral lesions ( $\geq 2$  cm<sup>2</sup>).

<b>Stage One</b>	Arthroscopic harvest of a small sample of healthy cartilage from a non-weight bearing area of the knee. Cartilage is then cultivated on a scaffold for 4-6 weeks in a lab.
<b>Stage Two</b>	Open procedure (arthrotomy) where the cartilage defect is exposed and debrided. The scaffold implant is placed in the defect and secured with fibrin sealant. This method avoids suture fixation used in second-generation ACI procedures.

### Types of Implantation Procedures

- **Matrix-Induced Autologous Chondrocyte Implantation (MACI):** Uses a thin scaffold seeded with chondrocytes.
- **NeoCart:** Chondrocytes grow and produce extracellular matrix throughout the scaffold.
- **NovoCart:** Full-thickness scaffold seeded with chondrocytes.

## Disclaimer

- **Progression:** Depends on time, soft tissue healing, patient demographics, and clinician evaluation

Recommendations	
<b>Expectations</b>	<ul style="list-style-type: none"> <li>• PT and CPM should start 7-10 days post-op</li> <li>• <b>Return to sport:</b> 12-15 months</li> <li>• Review operative report for lesion size and location, which may affect progression speed.</li> </ul>
<b>Risk Factors</b>	<ul style="list-style-type: none"> <li>• Extensive rehabilitation may exhaust insurance-approved PT visits</li> <li>• Consider reducing initial visit frequency, using a home NMES unit, and performing daily self-ROM</li> <li>• Long-term quadriceps strength deficits are common &gt;1 year post-operatively.</li> </ul>
<b>Concomitant Procedures</b>	<ul style="list-style-type: none"> <li>• Protocol should not change for multiple defects, meniscus repair, or ligamentous reconstruction.</li> <li>• Follow patellofemoral precautions if multiple defects include a patellofemoral lesion</li> <li>• <b>TTO Adjustments:</b> <ul style="list-style-type: none"> <li>➤ <i>At weeks 5-6:</i> Open brace to 0-35°</li> <li>➤ Perform all CKC interventions through protected ROM (90-45°) before transitioning to full ROM.</li> </ul> </li> </ul>

Weight Bearing Progression			
Region	Phase	Weeks	Weight Bearing
<b>Tibiofemoral (No Brace)</b>	<b>Phase 1</b>	Week 1	NWB
	<b>Phase 2</b>	Weeks 2-3	<i>Weeks 1-2: 25% BW to Week 3: 50% BW</i>
	<b>Phase 3</b>	Weeks 4-5	<i>Week 4: 60% BW to Week 5: 80% BW</i>
	<b>Phase 4</b>	Weeks 6-7	90% to 100% BW
	<b>Phase 5</b>	Weeks 8-	Full BW with normal gait pattern

Region	Phase	Weeks	Weight Bearing
		10	
<b>Patellofemoral (TROM Extension Brace)</b>	<b>Phase 1- 3</b>	Weeks 1-5	<ul style="list-style-type: none"> <li>• Full BW, brace locked in full extension</li> <li>• Open brace at week 5-6</li> </ul>
	<b>Phase 4</b>	Weeks 6-7	Discharge brace
	<b>Phase 5</b>	Weeks 8- 10	Normal gait without brace

### Range of Motion Progression

Phase	Weeks	ROM
<b>Phase 1/2</b>	Weeks 1-3	<i>Week 2: 0-45°</i> to <i>Week 3: 0-90°</i>
<b>Phase 3</b>	Weeks 4-5	<i>Week 4: 0-105°</i> to <i>Week 5: 0-120°</i>
<b>Phase 4</b>	Weeks 6-7	<i>Week 6: 0-125°</i> to <i>Week 7: 0-135°</i>
<b>Phase 5</b>	Weeks 8-10	<ul style="list-style-type: none"> <li>• Full AROM</li> <li>• Same ROM progression for tibiofemoral and patellofemoral lesions</li> </ul>

### Functional Testing

Test	Timing	Notes
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Test	Timing	Notes
Isometric Testing	4-5 months	At 90 degrees
Isokinetic Testing	6, 9, 12 months, and discharge	-
Hop Testing	After 80% symmetry achieved	<ul style="list-style-type: none"> <li>• SL hop for distance</li> <li>• Triple hop</li> <li>• Cross over hop</li> <li>• Timed 6m hop</li> </ul>

### Patient Reported Outcomes

Outcome Tool	Timing
KOOS	At initial evaluation, every 6 weeks, and discharge
IKDC	At initial evaluation, every 6 weeks, and discharge

### Criteria to Discharge

Criteria	Requirements
ROM	<ul style="list-style-type: none"> <li>• Full active knee extension</li> <li>• No pain on passive overpressure</li> </ul>
Strength	<ul style="list-style-type: none"> <li>• Strong quad isometric with full tetany and superior patellar glide</li> <li>• Able to perform 2x10 SLR without quad lag</li> </ul>
Effusion	1+ or less preferred (2+ <i>acceptable if all other criteria are met</i> )
Weight Bearing	Pain-free ambulation without visible gait deviation
<i>Tibiofemoral lesions</i>	<i>For 6-8 weeks: PWBing</i>

### Criteria to Initiate Running and Jumping

Criteria	Requirements
ROM	<ul style="list-style-type: none"> <li>• Full, pain-free knee ROM</li> </ul>

Criteria	Requirements
	<ul style="list-style-type: none"> <li>Symmetrical with the uninvolved limb</li> </ul>
<b>Strength</b>	<ul style="list-style-type: none"> <li>Isokinetic testing <i>80%</i> or greater for hamstring</li> <li>Quad at <i>60%/sec</i> and <i>300%/sec</i></li> </ul>
<b>Effusion</b>	1+ or less
<b>Weight Bearing</b>	<ul style="list-style-type: none"> <li>Normalized gait</li> <li>Jogging mechanics</li> </ul>
<b>Neuromuscular Control</b>	Pain-free hopping in place

Criteria for Return to Sport	
Criteria	Requirements
<b>ROM</b>	<ul style="list-style-type: none"> <li>Full, pain-free knee ROM</li> <li>Symmetrical with the uninvolved limb</li> </ul>
<b>Strength</b>	Isokinetic testing <i>90%</i> or greater for hamstring and quad at <i>60%/sec</i> and <i>300%/sec</i>
<b>Effusion</b>	No reactive effusion $\geq 1+$ with sport-specific activity
<b>Weight Bearing</b>	<ul style="list-style-type: none"> <li>Normalized gait</li> <li>Jogging mechanics</li> </ul>
<b>Neuromuscular Control</b>	Appropriate mechanics and force attenuation strategies with high-level agility, plyometrics, and high impact movements
<b>Functional Hop Testing</b>	LSI <i>90%</i> or greater for all tests
<b>Physician Clearance</b>	Required for return to sport

Chondrocyte Rehabilitation Maturation Phases		
Rehabilitation Phase	Stage of Repair	Tissue Maturation Timeline

Rehabilitation Phase	Stage of Repair	Tissue Maturation Timeline
Phase 1	Weeks 0-1	Initial Protection
Phase 2	Weeks 2-3	<i>For 0-6 weeks:</i> Implantation and Protection
Phase 3	Weeks 4-6	<i>For 6-12 weeks:</i> Early Transition and Proliferation
Phase 4	Weeks 7-12	<i>For 6-12 weeks:</i> Transition and Proliferation
Phase 5	Months 3-6	<i>For 12-26 weeks:</i> Remodeling
Phase 6	Months 6-9	Continued Remodeling
Phase 7	Months 9-RTS	<i>For 26 weeks onwards:</i> Maturation
<i>Graft will continue to remodel for up to 1 year post-op</i>		

Red/Yellow Flags		
Flag Type	Signs/Symptoms	Action Required
Red Flags	<ul style="list-style-type: none"> <li>Signs of DVT (e.g., localized tenderness, entire LE swelling, calf swelling &gt;3 cm compared to asymptomatic limb, pitting edema, collateral superficial veins)</li> <li>Mechanical block or clunk</li> <li>Lack of full knee extension by 4-6 weeks</li> </ul>	<ul style="list-style-type: none"> <li>Refer directly to ED for DVT</li> <li>Refer to surgeon for re-evaluation</li> </ul>
Yellow Flags	Persistent reactive pain or effusion following therapy or ADLs	<ul style="list-style-type: none"> <li>Decrease intensity of therapy interventions</li> <li>Continue effusion management</li> </ul>

Flag Type	Signs/Symptoms	Action Required
		<ul style="list-style-type: none"> <li>Provide patient education regarding activity modification until symptoms resolve</li> </ul>

### Phase I: Weeks 0-1

Aspect	Details
<b>Physical Therapy Start</b>	<ul style="list-style-type: none"> <li>Begin post-operative days 7-10</li> <li>Phase 1 completed independently through home exercises.</li> <li>Formal physical therapy starts in Phase 2.</li> </ul>
<b>Goal</b>	Maintain joint mobility and muscle tone while adhering to post-operative precautions.
<b>Range of Motion</b>	<ul style="list-style-type: none"> <li>0-45° ROM</li> <li><i>At day 7-10:</i> CPM to start</li> </ul>
<b>Weight Bearing</b>	<b>Tibiofemoral:</b> ≤20% BW <b>Patellofemoral:</b> Full BW, brace locked in full extension
<b>Suggested Interventions</b>	<ul style="list-style-type: none"> <li>Ankle pumps</li> <li>Quadriceps, hamstring, and gluteal isometric</li> <li>Diaphragmatic breathing</li> <li>Effusion management strategies, including RIC</li> </ul>

### Phase II: Weeks 2-3

Aspect	Details
<b>Goals</b>	<ul style="list-style-type: none"> <li>Achieve pain-free and full passive knee extension</li> <li>Maintain muscle tone</li> <li>Ensure proper wound healing and effusion management</li> </ul>
<b>Range of Motion</b>	0-90° Achieved through CPM and AAROM (heel slides, wall slides,

Aspect	Details
	AAROM row machine) <b>Total volume:</b> 300+ repetitions per day <b>Goal:</b> Early AROM through safe range
<b>Weight Bearing</b>	<b>Tibiofemoral:</b> 30% to 50% BW <b>Patellofemoral:</b> Full BW, brace locked in full extension
<b>Suggested Interventions</b>	<ul style="list-style-type: none"> <li>• Ankle pumps</li> <li>• Quadriceps, hamstring, and gluteal isometrics</li> <li>• Prone TKE</li> <li>• SLR-4 way</li> <li>• Patellar mobilization in all directions</li> <li>• Gait training</li> <li>• <b>Extension ROM:</b> Seated towel stretch, prone hang, bag hang</li> <li>• <b>Flexion ROM:</b> Heel slides, wall slides, AAROM row machine</li> <li>• <i>At week 3:</i> Recumbent cycling for ROM only (week 3)</li> <li>• SAQ (no resistance)</li> <li>• LAQ (no resistance, through protected ROM 90-45 degrees)</li> <li>• Continue CPM, effusion management, and NMES in long sitting</li> <li>• <b>For PF lesions only (in locked knee brace):</b> Weight shifting, DL heel raise, SL balance</li> <li>• NMES in long sitting</li> </ul>
<b>NMES Parameters</b>	<ul style="list-style-type: none"> <li>• Pads on proximal and distal quadriceps</li> <li>• Patient seated in long sitting (knees extended)</li> <li>• Relax while e-stim generates at least 50% of max volitional quadriceps contraction or maximal tolerable amperage without knee joint pain</li> <li>• <i>10-20 seconds on / 50 seconds off x 15 min</i></li> </ul>
<b>Criteria to</b>	<ul style="list-style-type: none"> <li>• Pain-free knee flexion of 90°</li> </ul>

Aspect	Details
<b>Progress to Phase 3</b>	<ul style="list-style-type: none"> <li>• Pain-free and full passive knee extension</li> <li>• Proficient heel-to-toe gait with 50% BW for tibiofemoral grafts or full BW for patellofemoral grafts</li> <li>• Reduced and well-controlled post-operative pain and edema</li> <li>• Ability to perform a strong isometric quadriceps contraction (full tetany and superior patellar glide)</li> <li>• Proficiency with home exercise program</li> </ul>

### Phase III: Weeks 4-6

Aspect	Details
<b>Goals</b>	<p>Increase knee flexion ROM</p> <p>Improve quadriceps, gluteal, and core strength</p>
<b>Range of Motion</b>	<p><i>At week 4: 0-105°</i></p> <p>to</p> <p><i>At week 6: 0-125°</i></p> <ul style="list-style-type: none"> <li>• Achieved through CPM and AAROM (heel slides, wall slides, AAROM row machine)</li> <li>• <b>Total volume:</b> 300+ repetitions per day</li> <li>• <b>Goal:</b> Early AROM through safe range</li> </ul>
<b>Weight Bearing</b>	<ul style="list-style-type: none"> <li>• <b>Tibiofemoral:</b> 60% BW (week 4) to 80% BW (week 5)</li> <li>• <b>Patellofemoral:</b> Full BW, open brace at weeks 5-6</li> </ul>
<b>Suggested Interventions</b>	<ul style="list-style-type: none"> <li>• Continue Phase 1 and 2 interventions</li> <li>• <b>SLR-Flexion progressions:</b> Semi-reclined or seated, add ER, perform with eyes closed, speed, isometric holds at end-range</li> <li>• Heel slides</li> <li>• Clamshells</li> <li>• Seated or standing hip ab/adduction (depending on WBing status)</li> <li>• Trunk stability interventions: TrA isometric progression,</li> </ul>

Aspect	Details
	<p>prone/side planks</p> <ul style="list-style-type: none"> <li>• Upright cycling (weeks 5-6)</li> <li>• Standing TKE (weeks 6-8)</li> <li>• Partial BW Shuttle Press (week 6-8)</li> <li>• OKC Hamstring strengthening (week 6-7)</li> <li>• Progress NMES to seated with tibia fixed at 60° of knee flexion</li> <li>• Discontinue CPM at 6 weeks</li> <li>• Continue effusion management strategies</li> </ul>
NMES Parameters	<ul style="list-style-type: none"> <li>• Pads on proximal and distal quadriceps</li> <li>• Patient seated with knee in at least 60° flexion, shank secured with strap, thigh strap preferred, ankle pad/belt 2 finger widths superior to lateral malleoli</li> <li>• Relax while e-stim generates at least 50% of max volitional contraction or maximal tolerable amperage without knee joint pain</li> <li>• 10-20 seconds on / 50 seconds off x 15 min</li> </ul>
Criteria to Progress to Phase 4	<ul style="list-style-type: none"> <li>• Pain-free active knee flexion to 125°</li> <li>• Pain-free gait with 80% BW for tibiofemoral grafts or full BW for patellofemoral grafts</li> <li>• 3x10 SLR without quadriceps lag</li> <li>• Proficiency with home exercise program</li> </ul>

#### Phase IV: Weeks 7-12

Aspect	Details
Goals	<p>Achieve movement independent of ambulation devices and knee braces</p> <p>Full ROM</p> <p>Initiate balance/proprioception interventions</p>
Range of Motion	<i>At week 6: 0-125°</i>

Aspect	Details
	<p style="text-align: center;"><i>At week 7: 0-135°</i></p> <p style="text-align: center;">to</p> <p style="text-align: center;"><i>At week 8-10: full ROM</i></p>
<b>Weight Bearing</b>	<ul style="list-style-type: none"> <li>• <b>Tibiofemoral:</b> <p style="text-align: center;"><i>At week 6: 90% BW</i></p> <p style="text-align: center;"><i>At week 7: 100% BW</i></p> <p style="text-align: center;">to</p> <p style="text-align: center;"><i>At week 10: Full WBing without obvious gait deviation</i></p> </li> <li>• <b>Patellofemoral:</b> Discharge brace</li> </ul>
<b>Suggested Interventions</b>	<ul style="list-style-type: none"> <li>• Continue Phase 2 and 3 interventions</li> <li>• Continue ROM interventions until symmetrical ROM achieved</li> <li>• <i>At week 6-8: Partial BW Shuttle Press</i></li> <li>• <i>At week 6-7: OKC Hamstring strengthening</i></li> <li>• Multi-angle isometrics</li> <li>• Balance and proprioception interventions</li> <li>• <i>At week 8-10: Mini squats: 0-45 degrees</i></li> <li>• <b><i>At weeks 10-12:</i></b> <ul style="list-style-type: none"> <li>• Heel Taps: 2-4"</li> <li>• Step Ups: 6-8"</li> <li>• Resisted OKC quadriceps strengthening through 90-45° protected ROM</li> <li>• Continue NMES (seated with tibia fixed at 60° of knee flexion)</li> <li>• Continue effusion management strategies as needed</li> </ul> </li> </ul>
<b>Criteria to Discharge</b>	<ul style="list-style-type: none"> <li>• <b>ROM:</b> Full active knee extension; no pain on passive overpressure</li> <li>• <b>Strength:</b> Strong quad isometric with full tetany and superior patellar glide</li> <li>• 2x10 SLR without quad lag</li> <li>• <b>Effusion:</b> 1+ or less preferred (2+ acceptable if all</li> </ul>

Aspect	Details
	<p>other criteria are met)</p> <ul style="list-style-type: none"> <li>• <b>Weight Bearing:</b> Pain-free ambulation without visible gait deviation</li> </ul>
<b>Criteria to Progress to Phase 5</b>	<ul style="list-style-type: none"> <li>• Pain-free active ROM</li> <li>• Pain-free ambulation without visible gait deviation</li> <li>• Proficiency in home exercise program</li> </ul>

### Phase V: Months 3-6

Aspect	Details
<b>Goals</b>	<p>Most patients return to part-time or full-time work</p> <p>Continue skilled physical therapy for functional and CKC strengthening</p>
<b>Range of Motion</b>	Full AROM
<b>Weight Bearing</b>	Full WBing, normal gait without brace
<b>Suggested Interventions</b>	<p><b>Continue Phase 3 and 4 interventions</b></p> <ul style="list-style-type: none"> <li>• Bridging</li> <li>• Standing SL calf raises</li> <li>• <i>At week 12-14:</i> Resisted OKC quadriceps strengthening through full ROM</li> <li>• Lunges</li> <li>• SL sit to stand through protected ROM</li> <li>• Elliptical</li> </ul> <p><b><i>At months 5-6:</i></b></p> <ul style="list-style-type: none"> <li>• Outdoor cycling</li> <li>• Rowing ergometry as tolerated</li> <li>• Continue NMES until 80% symmetry achieved</li> <li>• Continue effusion management as needed</li> </ul>
<b>Isometric Testing</b>	Appropriate at 4-4.5 months
<b>Criteria to Progress to</b>	<ul style="list-style-type: none"> <li>• Ability to negotiate stairs and mild gradients without</li> </ul>

Aspect	Details
<b>Phase 6</b>	<p>pain or reactive effusion</p> <ul style="list-style-type: none"> <li>• Return to work depending on job demands</li> <li>• Perform 3x10 heel raises on a 6” step with neutral alignment</li> <li>• Proficiency in home exercise program</li> </ul>

### Phase VI: Months 6-9

Aspect	Details
<b>Goals</b>	<ul style="list-style-type: none"> <li>• Progress OKC interventions</li> <li>• Perform strength testing to assess readiness for light plyometrics and walk-jog progression</li> </ul>
<b>Range of Motion</b>	Full AROM
<b>Weight Bearing</b>	<ul style="list-style-type: none"> <li>• Full WBing</li> <li>• Normal gait without brace</li> </ul>
<b>Suggested Interventions</b>	<ul style="list-style-type: none"> <li>• Continue <b>Phase 3-5</b> interventions</li> <li>• Increase difficulty of OKC exercises</li> <li>• Progress SL eccentric strengthening with body weight and machine interventions</li> <li>• Perform PBW jumping on the shuttle (DL to SL) once strength criteria are met</li> <li>• Progress to full body weight jumping</li> <li>• Walk-jog program</li> </ul>

### Isokinetic Testing and Criteria for Progression

Aspect	Details
<b>Isokinetic Testing</b>	<p>Appropriate at 6 and 9 months</p> <p>Reserved for patients returning to high-level activity</p>
<b>Criteria to Initiate Running and Jumping</b>	<b>1. ROM:</b> Full, pain-free knee ROM, symmetrical with the uninvolved limb

Aspect	Details
	<p><b>2. Strength:</b> Isokinetic testing shows 80% or greater for hamstring and quad at 60°/sec and 300°/sec</p> <p><b>3. Effusion:</b> 1+ or less</p> <p><b>4. Weight Bearing:</b> Normalized gait and jogging mechanics</p> <p><b>5. Neuromuscular Control:</b> Pain-free hopping in place</p>
<b>Criteria to Progress to Phase 7</b>	<p><i>By 9 months:</i></p> <ul style="list-style-type: none"> <li>• Quadriceps and hamstring symmetry of 80% or greater</li> <li>• Tolerate walking distances of 3 miles or more without reactive pain or effusion</li> <li>• Effectively negotiate uneven ground (e.g., soft sand) without pain or effusion</li> <li>• Return to pre-operative low-impact activities (cycling, elliptical, weight training)</li> </ul>

Phase VII: Months 9-Return to Sport	
Aspect	Details
<b>Goals</b>	<ul style="list-style-type: none"> <li>• Resume all normal functionality</li> <li>• Progress towards return to sport</li> </ul>
<b>Range of Motion</b>	Full AROM
<b>Weight Bearing</b>	Full WBing Normal gait without brace
<b>Suggested Interventions</b>	<ul style="list-style-type: none"> <li>• Continue Phase 3-6 interventions</li> <li>• Step-hold progression to SL hop</li> <li>• Sports-specific training</li> <li>• Agility</li> <li>• Plyometrics</li> </ul>
<b>Isokinetic Testing</b>	<ul style="list-style-type: none"> <li>• Appropriate at 12 months and discharge</li> </ul>

Aspect	Details
	<ul style="list-style-type: none"> <li>Reserved for high-level activity</li> </ul>
<p><b>Criteria to Return to Sport</b></p>	<ol style="list-style-type: none"> <li><b>ROM:</b> Full, pain-free knee ROM, symmetrical with the uninvolved limb</li> <li><b>Strength:</b> Isokinetic testing shows 90% or greater for hamstring and quad at 60%/sec and 300%/sec</li> <li><b>Effusion:</b> No reactive effusion <math>\geq 1+</math> with sport-specific activity</li> <li><b>Weight Bearing:</b> Normalized gait and jogging mechanics</li> <li><b>Neuromuscular Control:</b> Appropriate mechanics and force attenuation strategies for high-level agility, plyometrics, and high impact movements</li> <li><b>Functional Hop Testing:</b> LSI 90% or greater for all tests</li> <li><b>Physician Clearance</b></li> </ol>
<p><b>Activities to Avoid</b></p>	<p>High compression, shear, and rotational loads until 12-18 months</p> <p style="text-align: center;">OR</p> <p>As directed by the orthopedic surgeon</p>
<p><b>Full RTS Expected</b></p>	<p>Between 12-15 months post-operatively</p>