

# REHABILITATION GUIDELINES

Autologous Chondrocyte Implantation  
using Carticel®  
*(autologous cultured chondrocytes)*

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- THE FOLLOWING HAS BEEN PROVIDED AS GENERAL GUIDELINES FOR REHABILITATION FOLLOWING AUTOLOGOUS CULTURED CHONDROCYTE IMPLANTATION. INDIVIDUAL RESULTS MAY VARY. THE EMPHASIS OF THIS GUIDELINE IS TO PROTECT THE GRAFT SITE AND RETURN THE PATIENT TO AN OPTIMAL LEVEL OF FUNCTION. NOTWITHSTANDING THE FOREGOING, THE INFORMATION PROVIDED IN THIS DOCUMENT IS INTENDED FOR EDUCATIONAL PURPOSES. IT IS NOT A SUBSTITUTE FOR MEDICAL CARE NOR SHOULD IT BE CONSTRUED AS MEDICAL ADVICE. CONSULTATION WITH THE PATIENT'S TREATING SURGEON OR ORTHOPEDIST IS RECOMMENDED PRIOR TO IMPLEMENTING A REHABILITATION PROGRAM.
  - PATIENT ADHERENCE TO THE PRESCRIBED REHABILITATION PROGRAM IS IMPORTANT AND DEVIATION FROM THE PROGRAM MAY COMPROMISE CLINICAL BENEFIT FROM CARTICEL.
  - LESION SIZE, LOCATION AND PATIENT AGE ARE SIGNIFICANT FACTORS IN DETERMINING A REHABILITATION PROGRAM FOR EACH PATIENT.
  - ALTHOUGH TIME FRAMES HAVE BEEN ESTABLISHED, IT IS MORE IMPORTANT THAT GOALS ARE REACHED AT THE END OF EACH PHASE PRIOR TO PROGRESSION TO THE NEXT.
  - IT IS IMPORTANT TO AVOID EXCESSIVE LOADING/WEIGHT BEARING ON THE GRAFT SITE TO ENSURE PROPER HEALING. TAKE NOTE OF SPECIFIC PRECAUTIONS MENTIONED IN THE GUIDELINES. INFORMATION REGARDING THE LOCATION, SIZE, & SPECIFICS OF THE IMPLANTATION SITE SHOULD BE OBTAINED FROM THE SURGEON.
  - PAIN AND SWELLING NEED TO BE CAREFULLY MONITORED THROUGHOUT THE REHABILITATION PROCESS. IF EITHER OCCUR, THE ENSUING ACTIVITY NEEDS TO BE IDENTIFIED AND APPROPRIATELY ADJUSTED TO LESSEN THE IRRITATION. ICE PACKS MAY BE USED TO CONTROL SWELLING. IGNORING THESE SYMPTOMS MAY COMPROMISE THE SUCCESS OF THE SURGERY AND THE PATIENT'S OUTCOME.
  - AT ANYTIME DURING THE REHABILITATION PROCESS OR AFTER, IF SHARP PAIN WITH LOCKING OR SWELLING IS EXPERIENCED, THE PATIENT SHOULD NOTIFY THEIR PHYSICIAN.

## Indications

Carticel® is for autologous use and is indicated for the repair of symptomatic cartilage defects of the femoral condyle (medial, lateral or trochlea), caused by acute or repetitive trauma, in patients who have had an inadequate response to a prior arthroscopic or other surgical repair procedure. Carticel is not indicated for the treatment of cartilage damage associated with generalized osteoarthritis, and it is not recommended for patients with total meniscectomy unless surgically reconstructed prior to or concurrent with Carticel implantation.

## Important Safety Information

Any instability of the knee or malalignment of the joint should be corrected prior to or concurrent with Carticel implantation. It should not be used in patients with a known history of allergy to gentamicin, other aminoglycosides or materials of bovine origin. In addition, it should not be used in patients who have previously had cancer in the bones, cartilage, fat or muscle of the treated limb. Use in children, patients over age 65, or in joints other than the knee has not yet been assessed.

The occurrence of a subsequent surgical procedure, primarily arthroscopy, following Carticel implantation is common. Symptoms leading to arthroscopic intervention have included catching, locking, clicking or pain; patients who develop these symptoms should be evaluated and arthroscopy may be indicated for treatment or further assessment. In post-marketing surveillance, the most frequent operative findings, in descending order of frequency, were graft overgrowth, arthrofibrosis, graft delamination (partial or complete), joint adhesions, meniscus lesion or tear, chondromalacia, loose body, and joint malalignment. Refer to package insert for full prescribing and safety information.

# INTRODUCTION

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Articular cartilage defects of the knee are a common cause of pain and functional disability in the orthopedics and sports medicine practice. The avascular nature of articular cartilage predisposes the individual to progressive symptoms and degeneration due to the inability of articular cartilage to heal. The following paper will provide an overview of specific rehabilitation guidelines and the basic principles of Carticel<sup>®</sup> (autologous cultured chondrocytes) implantation rehabilitation. These suggested programs are designed using knowledge of basic science, anatomy, and biomechanics of articular cartilage as well as the natural course of healing following implantation and are not intended as a substitute for individual clinical judgement. The goal is to restore optimal function in each patient as quickly and safely as possible.

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# *Specific Rehabilitation* **GUIDELINES**

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One of the most important principles involved in Carticel® (autologous cultured chondrocytes) implantation rehabilitation is program individualization. Each patient will have a unique response to the surgical procedure and will therefore progress through rehabilitation at a different pace. Specific factors including lesion size and location, tissue quality, age, lifestyle, and general health will affect the patient's postoperative response. Therefore, these rehabilitation guidelines are designed to provide a general framework for exercise progression that will help return the patient to functional activities in a safe manner. Some patients may progress more rapidly, advancing range of motion and weight bearing status in a controlled fashion. The rehabilitation specialist should monitor joint line pain, effusion, and symptomatic complaints to determine if the patient is progressing appropriately. However, the rehabilitation program should continue to avoid deleterious forces to the graft site, including excessive compressive and shear forces, during exercise progression.

Rehabilitation varies per person based on age, weight, tissue quality, motivation, and activity level prior to surgery. Target timeframes noted in each phase are approximate and should be adjusted to the individual progress of each patient. Each person is different; rehabilitation progression is based on the size, location, quantity, containment, and quality of the defect, as well as the healing process after implantation.

The following section provides the rehabilitation guidelines for isolated femoral condyle and trochlea lesions<sup>1</sup>. There are four distinct phases based on the healing process following the implantation of Carticel. Certain criteria must be achieved prior to the patient progressing to each phase of the program. Specific goals and criteria to progress are listed under each phase. There is a great deal of variability from patient to patient. When a patient achieves the goals of a particular rehabilitation phase, he or she may be moved to the next phase at the surgeon's discretion.

Exercises are progressed based on the patient's subjective reports of symptoms, and the clinical assessment of swelling and crepitation. If pain or swelling occurs with any activities, they must be modified to decrease symptoms, and the orthopedic surgeon should be contacted.

Please see the VARIATIONS section (pages 14-16) for a discussion of recommended alterations to the basic rehabilitation guidelines that address concomitant procedures.

## CARTICEL IMPLANTATION Femoral Condyle Rehabilitation Guidelines

(Intended for small lesions (<5cm<sup>2</sup>) with no concomitant procedure;  
See “Rehabilitation Guideline Variations” section for others)

### PHASE I - PROTECTION PHASE (WEEKS 0-6)

#### Goals:

Protect healing tissue from load and shear forces	
Decrease pain and effusion	Restore full passive knee extension
Gradually improve knee flexion	Regain quadriceps control

#### Brace:

Locked at 0° during weight-bearing activities  
Sleep in locked brace for 2-4 weeks

#### Weight-Bearing:

Non-weight-bearing for 1-2 weeks, may begin toe-touch weight bearing immediately per physician instructions  
Toe touch weight-bearing (approx. 20-30 lbs) weeks 2-3  
Partial weight-bearing (approx. 1/4 body weight) at weeks 4-5

#### Range of Motion:

Motion exercise 6-8 hours post-operative  
Full passive knee extension immediately  
Initiate Continuous Passive Motion (CPM) day 1 for total of 8-12 hours/day (0°-40°) for 2-3 weeks  
Progress CPM Range of Motion (ROM) as tolerated 5°-10° per day  
May continue CPM for total of 6-8 hours per day for up to 6 weeks  
Patellar mobilization (4-6 times per day)  
Motion exercises throughout the day  
Passive knee flexion ROM 2-3 times daily  
Knee flexion ROM goal is 90° by 1-2 weeks  
Knee flexion ROM goal is 105° by 3-4 weeks and 120° by week 5-6  
Stretch hamstrings and calf

#### Strengthening Program:

Ankle pump using rubber tubing  
Quad setting  
Multi-angle isometrics (co-contractions Q/H)  
Active knee extension 90°-40° (no resistance)  
Straight leg raises (4 directions)  
Stationary bicycle when ROM allows  
Biofeedback and electrical muscle stimulation, as needed  
Isometric leg press by week 4 (multi-angle)  
May begin use of pool for gait training and exercises by week 4

#### Functional Activities:

Gradual return to daily activities	If symptoms occur, reduce activities to
Extended standing should be avoided	reduce pain and inflammation

#### Swelling Control:

Ice, elevation, compression, and edema modalities as needed to decrease swelling

#### Criteria to Progress To Phase II:

Full passive knee extension	Knee flexion to 120°
Minimal pain and swelling	Voluntary quadriceps activity

## **PHASE II - TRANSITION PHASE (WEEKS 6-12)**

### **Goals:**

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- Gradually increase ROM
- Gradually improve quadriceps strength/endurance
- Gradual increase in functional activities

### **Brace:**

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- Discontinue post-operative brace by week 6
- Consider unloading knee brace

### **Weight-Bearing:**

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- Progress weight-bearing as tolerated
- Progress to full weight-bearing by 8-9 weeks
- Discontinue crutches by 8-9 weeks

### **Range of Motion:**

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- Gradual increase in ROM
- Maintain full passive knee extension
- Progress knee flexion to 125°-135°
- Continue patellar mobilization and soft tissue mobilization, as needed
- Continue stretching program

### **Strengthening Exercises:**

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- Initiate weight shifts week 6
- Initiate mini-squats 0°-45°
- Closed kinetic chain exercises (leg press)
- Toe-calf raises
- Open kinetic chain knee extension progress 1 lb/week
- Stationary bicycle, low resistance (gradually increase time)
- Treadmill walking program
- Balance and proprioception drills
- Initiate front and lateral step-ups
- Continue use of biofeedback and electrical muscle stimulation, as needed
- Continue use of pool for gait training and exercise

### **Functional Activities:**

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- As pain and swelling (symptoms) diminish, the patient may gradually increase functional activities
- Gradually increase standing and walking

### **Criteria to Progress To Phase III:**

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- Full range of motion
- Acceptable strength level
  - Hamstrings within 10%-20% of contralateral leg
  - Quadriceps within 20%-30% of contralateral leg
- Balance testing within 30% of contralateral leg
- Able to walk 1-2 miles or bike for 30 minutes



### PHASE III: MATURATION PHASE (WEEKS 12-26)

#### Goals:

- Improve muscular strength and endurance
- Increase functional activities

#### Range of Motion:

- Patient should exhibit 125°-135° flexion

#### Exercise Program:

- Leg press (0°-90°)
- Bilateral squats (0°-60°)
- Unilateral step-ups progressing from 2" to 8"
- Forward lunges
- Walking program
- Open kinetic chain knee extension (0°-90°)
- Bicycle
- Stair machine
- Swimming
- Ski machine/Elliptical trainer

#### Functional Activities:

- As patient improves, increase walking (distance, cadence, incline, etc.)

#### Maintenance Program:

- Initiate by weeks 16-20
- Bicycle – low resistance, increase time
- Progressive walking program
- Pool exercises for entire lower extremity
- Straight leg raises
- Leg press
- Wall squats
- Hip abduction / adduction
- Front lunges
- Step-ups
- Stretch quadriceps, hamstrings, calf

#### Criteria to Progress to Phase IV:

- Full non-painful ROM
- Strength within 80%-90% of contralateral extremity
- Balance and/or stability within 75% of contralateral extremity
- Rehabilitation of functional activities causes no or minimal pain, inflammation or swelling.

## **PHASE IV - FUNCTIONAL ACTIVITIES PHASE (WEEKS 26-52)**

### **Goals:**

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Gradual return to full unrestricted functional activities

### **Exercises:**

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Continue maintenance program progression 3-4 times/week  
Progress resistance as tolerated  
Emphasis on entire lower extremity strength and flexibility  
Progress agility and balance drills  
Impact loading program should be specialized to the patient's demands  
Progress sport programs depending on patient variables

### **Functional Activities:**

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Patient may return to various sport activities as progression in rehabilitation and cartilage healing allows. Generally, low-impact sports such as swimming, skating, in-line skating, and cycling are permitted at about 6 months. Higher impact sports such as jogging, running, and aerobics may be performed at 8-9 months for small lesions or 9-12 months for larger lesions. High impact sports such as tennis, basketball, football, and baseball may be allowed at 12-18 months.

## CARTICEL® (autologous cultured chondrocytes) IMPLANTATION Trochlea Rehabilitation Guidelines

(Intended for small lesions (<5cm<sup>2</sup>) with no concomitant procedure;  
See “Rehabilitation Guideline Variations” section for others)

### PHASE I - PROTECTION PHASE (WEEKS 0-6)

#### Goals:

Protect healing tissue from load and shear forces	Restore full passive knee extension
Decrease pain and effusion	Regain quadriceps control
	Gradually improve knee flexion

#### Brace:

Locked at 0° during ambulation and weight-bearing activities  
Sleep in locked brace for 4 weeks

#### Weight Bearing:

Immediate partial weight-bearing in full extension, as tolerated	25% body weight with brace locked
	50% body weight by week 2 in brace
	75% body weight by weeks 3-4 in brace

#### Range of Motion:

Immediate motion exercise days 1-2  
Full passive knee extension immediately  
Initiate CPM on day 1 for total of 8-12 hours/day (0°-60°; if lesion > 6 cm<sup>2</sup> 0°-40°) for first 2-3 weeks  
Progress CPM ROM as tolerated 5°-10° per day  
May continue use of CPM for total of 6-8 hours per day for 6 weeks  
Patellar mobilization (4-6 times per day)  
Motion exercises throughout the day  
Passive knee flexion ROM 2-3 times daily  
Knee flexion ROM goal is 90° by 2-3 weeks  
Knee flexion ROM goal is 105° by 3-4 weeks, and 120° by week 6  
Stretch hamstrings, calf

#### Strengthening Program:

Ankle pump using rubber tubing  
Quad setting  
Straight leg raises (4 directions)  
Toe-calf raises by week 2  
Stationary bicycle when ROM allows  
Biofeedback and electrical muscle stimulation, as needed  
Isometric leg press by week 4 (multi-angle)  
Initiate weight shifts by week 4  
May begin pool therapy for gait training and exercise by week 4

#### Functional Activities:

Gradual return to daily activities	If symptoms occur, reduce activities
Extended standing should be avoided	to reduce pain and inflammation
Use caution with stair climbing	

#### Swelling Control:

Ice, elevation, compression, and edema modalities as needed  
to decrease swelling

#### Criteria to Progress To Phase II:

Full passive knee extension	Knee flexion to 115°–120°
Minimal pain and swelling	Voluntary quadriceps activity

## **PHASE II - TRANSITION PHASE (WEEKS 6-12)**

### **Goals:**

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- Gradually increase ROM
- Gradually improve quadriceps strength/endurance
- Gradually increase functional activities

### **Brace:**

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- Discontinue brace by 6 weeks

### **Weight-Bearing:**

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- Progress weight-bearing as tolerated
- Progress to full weight-bearing by 6-8 weeks
- Discontinue crutches by 6-8 weeks

### **Range of Motion:**

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- Gradually increase ROM
- Maintain full passive knee extension
- Progress knee flexion to 120°-125° by week 8
- Continue patellar mobilization and soft tissue mobilization, as needed
- Continue stretching program

### **Strengthening Exercises:**

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- Closed kinetic chain exercises (leg press 0°-60°) by week 8
- Initiate mini-squats 0°-45° by week 8
- Toe-calf raises
- Open kinetic chain knee extension without resistance
- Begin knee extension 0°-30° then progress to deeper angles
- Stationary bicycle (gradually increase time)
- Stair machine at week 12
- Balance and proprioception drills
- Initiate front and lateral step-ups
- Continue use of biofeedback and electrical muscle stimulation, as needed

### **Functional Activities:**

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- As pain and swelling (symptoms) diminish, the patient may gradually increase functional activities
- Gradually increase standing and walking

### **Criteria to Progress To Phase III:**

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- Full range of motion
- Acceptable strength level
  - Hamstrings within 10%-20% of contralateral leg
  - Quadriceps within 20%-30% of contralateral leg
- Balance testing within 30% of contralateral leg
- Able to walk 1-2 miles or bike for 30 minutes

### PHASE III: REMODELING PHASE (WEEKS 13-32)

#### Goals:

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- Improve muscular strength and endurance
- Increase functional activities

#### Range of Motion:

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- Patient should exhibit 125°-135° flexion

#### Exercise Program:

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- Leg press (0°-60°; progress to 0°-90°)
- Bilateral squats (0°-60°)
- Unilateral step-ups progressing from 2" to 6"
- Forward lunges
- Walking program on treadmill
- Open kinetic chain knee extension (90°-40°) – progress 1 lb every 10-14 days if no pain or crepitation – must monitor symptoms
- Bicycle
- Stair machine
- Swimming
- Ski machine/Elliptical trainer

#### Functional Activities:

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- As patient improves, you may increase walking (distance, cadence, incline, etc.)
- Light running can be initiated toward end of phase based on physician evaluation

#### Maintenance Program:

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- Initiate by weeks 16-20
- Bicycle – low resistance, increase time
- Progressive walking program
- Pool exercises for entire lower extremity
- Straight leg raises
- Leg press
- Wall squats
- Hip abduction / adduction
- Front lunges
- Step-ups
- Stretch quadriceps, hamstrings, calf

#### Criteria to Progress to Phase IV:

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- Full non-painful ROM
- Strength within 80%-90% of contralateral extremity
- Balance and/or stability within 75% of contralateral extremity
- Rehabilitation of functional activities causes no or minimal pain, inflammation or swelling.

## **PHASE IV - MATURATION PHASE (8-15 MONTHS)**

### **Goals:**

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Gradually return to full unrestricted functional activities

### **Exercises:**

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Continue maintenance program progression 3-4 times/week

Progress resistance as tolerated

Emphasize on entire lower extremity strength & flexibility

Progress agility and balance drills

Progress walking program as tolerated

Impact loading program should be specialized to the patient's demands

No jumping or plyometric exercise until 12 months

Progress sport programs depending on patient variables

### **Functional Activities:**

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Patient may return to various sport activities as progression in rehabilitation and cartilage healing allows. Generally, low-impact sports such as swimming, skating, in-line skating, and cycling are permitted at about 6 months. Higher impact sports such as jogging, running, and aerobics may be performed at 8-9 months for small lesions or 9-12 months for larger lesions. High impact sports such as tennis, basketball, football, and baseball may be allowed at 12-18 months.



# Rehabilitation Guideline VARIATIONS

Additional surgical procedures to address patellofemoral and tibiofemoral alignment, ligamentous laxity, and meniscal pathology are often performed at the time of the Carticel® (autologous cultured chondrocytes) implantation to minimize possible contributing factors to graft failure due to excessive compressive and shear forces. Rehabilitation programs for Carticel may often require alterations based on the unique presentation of each patient. The next section will briefly discuss variations to the isolated guidelines previously discussed based on the extent of lesion damage and concomitant procedures performed.

## Anterior Cruciate Ligament Reconstruction

Reconstruction of the anterior cruciate ligament (ACL) using an ipsilateral patellar tendon graft generally requires an increased rate of passive ROM restoration. Harvesting the ipsilateral patellar tendon may predispose the patient to the development of arthrofibrosis and loss of motion due to excessive scar tissue formation in the anterior aspect of the knee. Emphasis is placed on full passive knee extension and patellar mobilizations immediately following surgery. Passive ROM is slightly accelerated for a femoral condyle implantation during the initial phase of rehabilitation with the goals of 90° of passive knee flexion by week 1, 100°-105° by week 2, 115° by week 4, 125° by week 6, and 135° by week 8. Weight-bearing precautions and exercise progression are similar to the isolated femoral condyle guideline.

Lesions on the trochlea with a concomitant ACL reconstruction require a more conservative approach than condyle lesions. Passive ROM is progressed slowly at first from 45° by day 3, to 60°-75° by day 7, 90° by day 10, 100° by day 14, 105° by week 3, 115° by week 4, and 125° by week 6. Partial weight bearing is typically performed immediately in a brace locked in extension similar to an isolated trochlea lesion.

The use of a hamstring autogenous graft for ACL reconstruction involves similar guidelines as the patellar tendon graft. However, caution should be taken with overaggressive hamstring strengthening in the early postoperative phases to minimize graft site morbidity. Aggressive strengthening of the hamstrings should typically be avoided for the first 6-8 weeks.

Allograft tissue may also be used for ACL reconstruction. Rehabilitation does not differ significantly from an autogenous graft although the patient may feel less anterior knee pain due to minimized graft morbidity.

## Meniscal Allograft

Meniscal allograft transplantation alters the rehabilitation program significantly to allow healing of the meniscus postoperatively. While weight bearing guidelines are similar to that of the isolated femoral condyle guidelines, ROM and exercise progression is altered. The rate of passive ROM restoration is slightly decelerated to protect the meniscus with the goals of 60° of knee flexion by week 1, 90° by week 2, 100° by week 5, 110° week 6, 120° by week 7, and 125° by week 8. No active knee flexion past 90° should be allowed for the first 6-8 weeks to minimize strain on the meniscus due to the close anatomical



relationship of the hamstrings, capsular tissue, and meniscus. Furthermore, resisted hamstring strengthening is typically avoided until week 12. The use of bicycle and pool therapy usually begins by week 6-8.

### Distal Realignment

A distal realignment, involving an anteromedialization of the tibial tubercle, is often performed during trochlea implantations. Several aspects of the rehabilitation program should be altered to avoid excessive strain on the tibial tubercle. Passive ROM should be progressed slowly with the goals of 45° by day 5, 60° by the end of week 1, 75° by week 3, 90° by week 4, 115° by week 5, 125° by week 6, and 125°-135° by week 8. Weight-bearing progression is similar to that of the isolated trochlea guidelines with immediate partial weight bearing with a knee brace locked in full extension. Scar tissue management and patellar mobilizations are recommended to be performed to minimize the formation of adhesions. Open kinetic chain knee extensions can be initiated without resistance from 60°-0° by weeks 6-8 as tolerated. The use of a bicycle and pool therapy can be initiated by weeks 6-8.

### High Tibial Osteotomy

A high tibial osteotomy to realign the tibiofemoral joint generally requires a slightly accelerated passive ROM progression to avoid motion loss postoperatively with the goals of 90° of knee flexion by week 1, 105° by week 2, 115° by week 3, 125° by week 4, and a gradual progression past 125° beginning by week 6. Weight-bearing progression is similar to that of the isolated femoral condyle lesion, although weight-bearing may be delayed based on radiographic evidence of bone formation, if bone

grafting is used, lesion size or location. Emphasis should be placed on restoring strength and flexibility of the quadriceps for optimal joint function. Furthermore, the use of external devices to alter the applied load of the tibiofemoral joint may be used such as orthotics, insoles, and heel wedges. The use of an osteoarthritis unloading brace is recommended when the postoperative knee brace is discharged by weeks 6-8.

### Lesion Size

The rehabilitation program may also vary based on the size of the lesion due to a larger area of articulation during weight bearing and exercises. The exact variation will differ based on the location of the lesion, although a larger lesion is generally considered to be 5 cm<sup>2</sup> or greater.

Larger lesions on the femoral condyles will generally necessitate a slower weight-bearing progression, particularly for the medial femoral condyle in the varus-aligned knee. Typically, weight-bearing progression is delayed 2-4 weeks. Full weight bearing without the use of crutches is progressed to by weeks 10-12, and may be longer for more complicated lesions. The use of an unloader brace is recommended to decrease compressive forces to the graft site.

Conversely, large lesions on the trochlea may still progress with the same weight-bearing guidelines as smaller lesions. However, range of motion may be slightly delayed to minimize shear forces at the patellofemoral. Knee flexion passive range of motion should be progressed based on a patient's report of pain or symptoms. In general, ROM is performed from 0°-45° during the first week, progressing to 75° by week 2, 90° by week 3, 100°-105° by week 4, progressing to 120° by weeks 6-8. Open kinetic chain active knee extension

exercises should also be avoided for large trochlea lesions until week 10 and are then progressed slowly with low resistance. Aggressive resisted knee extension exercises should be avoided for 9-12 months.

### **Uncontained Lesion**

Large lesions are often uncontained lesions. The presence of an uncontained lesion will alter the weight-bearing progression due to the complexity of the repair and the stability of the suture fixation. The rehabilitation program should be altered similar to the guidelines for large condyle or trochlea lesions. Therefore, for uncontained condyle lesions, the weight-bearing progression is typically delayed approximately 2-4 weeks, and for uncontained trochlea lesions the range of motion and exercise programs are decelerated similar to large lesions. Heavy resisted open kinetic chain exercises should be avoided for at least 3-6 months postoperatively on the femur and 9-12 months on the trochlea. The rehabilitation progression will be highly individualized for these patients based on the physician's discretion and the size and containment of the lesion.

### **Osteochondritis Dissecans**

The rehabilitation program for a Carticel® (autologous cultured chondrocytes) implantation procedure to address an osteochondritis dissecans does not vary considerably in terms of immediate postoperative weight bearing, range of motion, or exercises guidelines. However, when the patient begins returning to functional activities during the later phases of rehabilitation, a slower approach is typically utilized. A return to low impact activities is usually delayed for at least 6 months

postoperative. Emphasis should be placed on a gradual program of walking by 6-8 months, progressing to light jogging and running by 8-9 months, and eventually jumping by 9-12 months postoperative at the earliest.

In the event that a bone grafting procedure is needed concomitantly, the patient should be non-weight bearing for approximately 2-4 weeks, progressing to full weight bearing by 12-16 weeks.

### **Multiple Lesions**

The presence of multiple lesions will alter the rehabilitation program based on the location of each lesion, and will typically involve a more conservative postoperative program. For multiple lesions on the femoral condyles or trochlea, the rehabilitation program is adjusted similar to the guidelines for a large condylar or trochlea lesion, respectively. However, the combination of a lesion on the condyle as well as the trochlea will vary significantly. The rehabilitation program should take into consideration the precautions of both lesion sites. Therefore, the weight-bearing progression would typically assume the postoperative precautions similar to an isolated femoral condyle lesion to avoid overaggressive compressive forces. Conversely, the range of motion and exercise progression would typically assume the postoperative precautions similar to a trochlea lesion to avoid detrimental shear forces. Thus the patient should be non-weight bearing for 2 weeks postoperative, progressing to 25% body weight by week 5, 50% body weight by week 6, and gradually progressing to full weight bearing by weeks 9-12 based on lesion specifics. Knee flexion range of motion should progress to 90° by week 3, 105° by week 4, and 120° by week 6. Lesion size may further delay the range of motion and weight-bearing progression.

# VARIATIONS

# PRINCIPLES of Carticel® (autologous cultured chondrocytes) Implantation Rehabilitation

There are several key principles involved when designing rehabilitation programs following Carticel implantation. These key principles include: creating a healing environment, the biomechanics of the knee, restoring soft tissue balance, reducing post-operative pain, restoring muscle function, gradually progressing applied loads, and team communication. We briefly describe each one as they relate to the rehabilitation program.

## Create a Healing Environment

The first principle of Carticel rehabilitation involves creating an environment that facilitates the repair process while avoiding potentially deleterious forces to the graft site. This involves a thorough knowledge of the physiological repair process following implantation. Through animal studies, as well as the close monitoring of the maturation of the repair tissue in human patients via arthroscopic examination, four different biological phases of maturation have been identified.<sup>2-6</sup>

The first phase is the proliferation-protection phase, which usually involves the first six weeks following cell implantation. During the first 24 hours after cell implantation, the cells line the base of the lesion, proliferate and produce a matrix that will fill the defect with a soft repair tissue up to the level of the periosteal cover. Passive range of motion and controlled partial weight bearing will help promote cell function. During this initial phase, controlled active and passive

range of motion and a gradual weight-bearing progression are critical components to the rehabilitation process.

Controlled compression and decompression forces observed during weight bearing may provide the signals to the chondrocytes to produce an appropriate matrix. A progression of partial weight bearing with crutches is used to gradually increase the amount of load applied to the weight-bearing surfaces of the joint. The use of a pool or aquatic therapy may be beneficial to begin gait training and lower extremity exercises. The buoyancy of the water decreases the amount of weight-bearing forces to approximately 25% body weight with a water depth to the axilla, and 50% with water depth to the waist.<sup>7</sup> Thus a pool may be used during early phases of rehabilitation to perform limited weight-bearing activities.

Passive range of motion activities, such as continuous passive motion (CPM) machines, are also generally performed 6-8 hours after surgery to nourish the healing articular cartilage and prevent the formation of adhesions. CPM usage is typically performed for at least 2-3 weeks, with recommended usage up to 6-8 weeks. The CPM is recommended for approximately 6-8 hours per day, which may be broken into 2-3 hour segments. Motion exercises may assist in creating a smooth, low frictional surface by sliding against the joint's articular surface. The use of CPM has been shown to enhance cartilage healing and long-term outcomes following articular cartilage procedures.<sup>8,9</sup>

The second phase is the transitional-protective phase, which typically includes weeks 7 through 12. The repair tissue at this point is spongy and compressible with little resistance. Upon arthroscopic

examination, the tissue may, in fact, have a wave-like motion to it when sliding a probe over the tissue. During this phase, the patient usually progresses from partial weight bearing to full weight bearing. Continued maturation of the repair tissue is fostered through higher level functional and motion exercises. It is during this phase that patients typically resume most normal activities of daily living.

The third phase is known as the remodeling-functional phase, and typically occurs from 12 weeks through 32 weeks postoperatively. During this phase there is usually a continuous production of matrix with further remodeling into a more organized structural tissue. The tissue at this point has the consistency of soft plastic upon probing. As the tissue becomes more firm and integrated, it allows for more functional training activities to be performed. At this point, the patient typically notes improvement of symptoms and has generally normal motion.

The final phase is known as the maturation and optimization phase, and can last up to 15 to 18 months post-implantation depending upon the size and location of the lesion. It is during this phase that the repair tissue usually reaches its full maturation. The stiffness of the cartilage resembles that of the surrounding tissue.<sup>5,6</sup>

### Biomechanics of the Knee

The next rehabilitation principle involves the biomechanics of the tibiofemoral and patellofemoral joint during normal joint articulation.

Articulation between the femoral condyle and tibial plateaus is constant throughout knee range of motion. The anterior

surface of the femoral condyles is in articulation with the middle aspect of the tibial plateau near full knee extension. As the knee moves into greater degrees of knee flexion, the femoral condyles progressively roll and slide posteriorly, causing articulation to shift posteriorly on the femoral condyle and tibial plateaus.<sup>10,11</sup>

Articulation between the inferior margin of the patella and the trochlea begins at approximately  $10^{\circ}$  –  $20^{\circ}$  of knee flexion.<sup>11</sup> As the knee proceeds into greater degrees of knee flexion, the contact area of the patellofemoral joint moves proximally along the patella. At  $30^{\circ}$ , the area of patellofemoral contact is approximately  $2\text{ cm}^2$ .<sup>11</sup> The area of contact gradually increases as the knee is flexed. At  $90^{\circ}$  of knee flexion, contact area increases up to approximately  $6\text{ cm}^2$ .<sup>12</sup>

Using this knowledge of the joint kinematics, the rate of weight bearing and passive range of motion may be progressed based on the exact location of the lesion. For example, a lesion on the anterior aspect of the femoral condyle may be progressed into deeper degrees of passive knee flexion without causing articulation at the graft site. Conversely, lesions on the posterior condyle may require a slower rate of passive range of motion progression due to the progressive rolling and sliding component of articulation during deeper flexion. Furthermore, lesions on a non-weight-bearing surface, such as the trochlea, may include immediate partial weight bearing with a brace locked in full knee extension without causing excessive compression on the graft site. The use of a postoperative brace is recommended to assure that weight bearing is performed in a non-articulating range of motion.

Rehabilitation exercises can be altered based on the biomechanics of the knee to avoid excessive compressive or shearing forces. Open kinetic exercises, such as knee extension, are commonly performed from 90° – 40° of knee flexion. This range of motion provides the lowest amount of patellofemoral joint reaction forces while exhibiting the greatest amount of patellofemoral contact area.<sup>11-13</sup> Closed kinetic chain exercises, such as the leg press, vertical squats, lateral step-ups, and wall squats, are best performed initially from 0° to 30° and then progressed to 0° to 60° where tibiofemoral and patellofemoral joint reaction forces are lowered.<sup>11-13</sup> As the graft site heals and patient symptoms subside, the ranges of motion should be progressed to allow greater muscle strengthening in larger ranges. Exercises are progressed based on the patient's subjective reports of symptoms, and the clinical assessment of swelling and crepitation. If pain or swelling occurs with any activities, they must be modified to decrease symptoms, and the orthopedic surgeons should be contacted.

### **Restore Soft Tissue Balance**

One of the more important aspects of Carticel® (autologous cultured chondrocytes) rehabilitation involves the avoidance of arthrofibrosis. This is usually achieved by focusing on the restoration of full knee extension, patella mobility, and soft tissue flexibility of the knee and entire lower extremity. The inability to fully extend the knee may result in abnormal joint kinematics and subsequent increases in patellofemoral and tibiofemoral joint contact pressure, strain on the quadriceps muscle, and muscular fatigue.<sup>15</sup> Several authors have reported that immediate (post-operative

day 1) motion is essential to avoid range of motion complications and minimize poor functional outcomes.<sup>16, 17</sup> Therefore, a drop-lock post-operative knee brace locked into 0° of extension is generally used, and CPM and passive range of motion out of the brace are typically performed 6-8 hours following surgery.

The goal is to achieve at least 0° of knee extension the first few days post-operatively. Specific exercises utilized may include manual passive range of motion exercises performed by the rehabilitation specialist, supine hamstring stretches with a wedge under the heel, and gastrocnemius stretching with a towel. Overpressure of 6-12 pounds may be used for a low-load, long-duration stretch as needed to achieve full extension.

Patients will often exhibit a certain amount of hyperextension preoperatively or in the uninvolved knee. For patients with significant hyperextension of the uninvolved extremity, regaining approximately 5°-7° of hyperextension through stretching techniques in the clinic is suggested. The remaining hyperextension may be achieved through functional activities. We believe this allows the patient to gain a greater degree of neuromuscular control at the end range of extension, and avoids uncontrolled and unexpected hyperextension movements.

The loss of patellar mobility following Carticel implantation may be due to various reasons, including excessive scar tissue adhesions along the medial and lateral gutters. The loss of patellar mobility may result in range of motion complications and difficulty recruiting quadriceps contraction. Patellar mobilizations in the medial-lateral and

superior-inferior directions can be performed by the rehabilitation specialist and independently by the patient during their home exercise program.

Soft tissue flexibility and pliability are also important for the entire lower extremity. Soft tissue massage and scar management can be performed to prevent adhesion development around the anterior, medial, and lateral aspects of the knee. In addition, flexibility exercises can be performed for the entire lower extremity, including the hamstrings, hip, and calf musculature.

Post-operative adhesion formation may result in range of motion complications. The most beneficial treatment for arthrofibrosis is prevention. Early emphasis on extension and flexion range of motion, patella mobilizations, and continuous passive range of motion at home is important to help prevent arthrofibrosis. It is essential that the patient achieve full knee extension immediately following surgery. This may be facilitated through the use of passive extension range of motion, hamstring stretching, and gastrocnemius stretching. In the event that the patient develops flexion or extension range of motion complications, the rehabilitation specialist may perform several therapeutic techniques. These can include moist heat, ultrasound to the anterior knee, scar and soft tissue mobilizations, patellar mobilizations, and passive range of motion and flexibility exercises. Low-load, long-duration stretches to achieve full knee extension may also be performed in the supine position, incorporating a wedge underneath the patient's heel and concomitant weight (ranging from 5-12 pounds) applied to the distal thigh, typically for 10-12 minutes.

Although not common, it is possible for adhesions to form and attach to the healing graft site. Therefore, caution should be used to avoid the development of arthrofibrosis. In the event that severe adhesions develop with loss of motion, the surgeon may perform an arthroscopic lysis of adhesions. Manual manipulations are not commonly performed for Carticel patients due to the possibility of adhesion formation to the graft site.

Furthermore, as the chondrocytes grow and mature, graft hypertrophy may occur in a small number of patients, resulting in subjective reports of clicking and popping at approximately 3 months post-operatively. This may be addressed by modifying active and closed kinetic chain exercises to be performed with lighter resistance or in a symptom-free range of motion. Passive range of motion should continue to be performed to assist in the formation of a smooth articulation.

Emphasis of the rehabilitation program at this point is to facilitate a smooth, low-friction articular surface through the use of controlled passive range of motion and compressive loading (without shear). Passive range of motion exercises should be performed manually by the rehabilitation specialist, as well as independently by the patient periodically throughout the day. It is recommended that the patient perform passive range of motion 4-6 times per day. Furthermore, the use of low resistance bicycle riding and aquatic therapy is recommended.

### **Reduction of Pain & Effusion**

Numerous authors have studied the effect of pain and joint effusion on muscle inhibition. A progressive decrease in quadriceps activity has been noted as the knee exhibits increased pain and distention.<sup>18, 19</sup> Thus, the reduction in knee joint pain and swelling post-operatively is crucial to restore normal volitional quadriceps activity. Treatment options for pain and/or swelling may include analgesics, cryotherapy, high-voltage stimulation, ultrasound, and joint compression.

### **Restoring Muscle Function**

The next principle involves restoring muscle function of the lower extremity. Inhibition of the quadriceps muscle is a common clinical enigma in the presence of pain and effusion during the acute phases of rehabilitation immediately following the implementation of Carticel® (autologous cultured chondrocytes). Electrical muscle stimulation and biofeedback are often incorporated with therapeutic exercises to facilitate the active contraction of the quadriceps musculature. This appears to facilitate the return of muscle activation and may be valuable additions to therapeutic exercises.<sup>20</sup>

Electrical stimulation may be used post-op day one while performing isometric and isotonic exercises such as quadriceps sets, straight leg raises, hip adduction and abduction, and knee extensions. Electrical stimulation may be used prior to biofeedback when the patient presents acutely with the inability to activate the quadriceps musculature. Once independent muscle activation is present, biofeedback may be utilized to facilitate further neuromuscular activation of the

quadriceps. The patient must concentrate on neuromuscular control to independently activate the quadriceps during rehabilitation.

Exercises that strengthen the entire lower extremity, such as machine weights and closed kinetic chain exercises, should be included as the patient progresses to more advanced phases of rehabilitation. It is important that total leg strength be emphasized rather than concentrating solely on the quadriceps. Training of the hip, pelvis, core, and ankle located proximally and distally along the kinetic chain should be emphasized to assist in controlling force production and dissipation in the knee. In addition, the hip and ankle assist in controlling abduction and adduction moments at the knee joint.

Proprioceptive and neuromuscular control drills of the lower extremities should also be included to restore dynamic stabilization of the knee joint postoperatively. Specific drills initially could include weight shifting side-to-side, weight shifting diagonally, mini-squats, and mini-squats on an unstable surface such as a tilt board (usually during Phase I of rehabilitation). Perturbations can further be added to challenge the neuromuscular system (usually during Phase II of rehabilitation). Additional exercises that may be performed include lateral lunges onto unstable surfaces and balance beam walking (usually during Phase III of rehabilitation).

### **Gradual Progression of Applied Loads**

The next principle of Carticel rehabilitation involves gradually increasing the amount of stress applied to the injured knee as the patient returns to functional activities. The



progression of weight-bearing and range of motion restoration, as previously discussed, involves a gradual advancement to assure that complications such as excessive motion restrictions or scar tissue formation are avoided while progressing steadily to avoid overstressing the healing graft site. An overaggressive approach early within the rehabilitation program may result in increased pain, inflammation, or effusion, as well as graft damage. This simple concept may be applied to the progression of strengthening exercises, proprioception training, neuromuscular control drills, and functional drills. For example, exercises such as weight shifts and lunges can be progressed from straight plane anterior-posterior or medial-lateral directions to involve multi-plane and rotational movements. Exercises using two legs, such as leg press and balance activities, can be progressed to single-leg exercises. Thus, the progression through the post-operative rehabilitation program involves a gradual progression of applied and functional stresses. This progression is used to provide a healthy stimulus for healing tissues while assuring that forces are gradually applied without causing damage.

Additionally, Carticel patients may benefit from use of orthotics, insoles, and bracing to alter the applied loads on the articular cartilage during functional activities. These devices can be used to avoid excessive forces by unloading the area of the knee where the implantation is located. Unloader braces are often used for patients with subtle uncorrected abnormal alignments (genu varum) and large or uncontained lesions, as well as in the presence of concomitant osteotomies and meniscal allografts.

### **Team Communication**

An important principle of Carticel implantation rehabilitation involves a team approach between the surgeon, physical therapist, and patient. Communication between the surgeon and therapist is essential to determine an accurate rate of progression based on the location of the lesion, size of the lesion, tissue quality of the patient, and the addition of concomitant surgical procedures. Also, communication between the medical team and patient is essential to provide patient education regarding the avoidance of deleterious forces, as well as compliance with precautions. Often, a preoperative physical therapy evaluation may be useful to mentally and physically prepare the patient for the Carticel procedure and post-operative rehabilitation. Often times, the patient may become pain free earlier than expected, potentially endangering the Carticel implantation. As a general matter, the clinician should communicate to the patient that, although they may experience minimal symptoms, they should adhere strictly to the rehabilitation guidelines.

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This protocol has been established as a guideline only.  
Each patient must be assessed separately and the rehabilitation modified accordingly by the treating medical professionals.

A microscopic view of cells, likely chondrocytes, showing various shapes and sizes, some with prominent nuclei, set against a green background.

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