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CLINICAL COMMENTARY

OSTEOCHONDRAL ALLOGRAFT TRANSPLANTATION FOR THE KNEE: POST-OPERATIVE REHABILITATION

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ABSTRACT

Articular cartilage injuries of the knee are common among young, active patients presenting with knee pain, swelling, and/or mechanical symptoms. These injuries have limited healing potential due to the avascular nature of hyaline cartilage. While several treatment options exist, osteochondral allograft (OCA) transplantation for the knee has been used successfully in primary management of large chondral or osteochondral defects and salvage of previously failed cartilage repair. OCA transplantation potentially yields a natural, matching contour of the native recipient surface anatomy and transplants mature, viable hyaline cartilage to the affected defect. Following OCA transplantation, strict compliance with a rehabilitation protocol is essential to enable optimal recovery. The outlined rehabilitation protocol is informed by the existing literature and incorporates current rehabilitation principles, the science of osteochondral incorporation, and adaptations based on an individual's readiness to progress through subsequent phases. The purpose of this clinical commentary is to discuss the diagnosis, surgical management, and post-operative rehabilitation following OCA transplantation and to assist the physical therapist in returning athletes to full sports participation.

Key Words: cartilage, knee, osteochondral allograft, rehabilitation

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BACKGROUND AND PURPOSE

Chondral injuries of the knee manifest in a variety of sizes, depths, and locations and present across a spectrum of severity, ranging from small, isolated, shallow lesions to large, multifocal, full-thickness defects.[1] Knee chondral injuries tend to occur in young, active patients, and have been identified in approximately 60% of patients undergoing knee arthroscopy.[2-5] Articular cartilage defects may occur with acute trauma or repetitive overloading, resulting in softening of the cartilage, fissuring, flap tears or delamination.

Chondral injuries have limited healing potential due to the avascular nature of hyaline cartilage[6,7] and present a complex treatment scenario. A number of factors must be considered when making treatment decisions, such as lesion location, defect size and depth, and individual patient characteristics, such as age and activity level.[1,8-10] Current decision-making, based on defect geometry and patient characteristics, progresses linearly from non-operative to operative treatment, including palliative, reparative or restorative surgery.[11]

Small (<0.5-1 cm^2) and/or superficial (grade I or II) lesions, as well as diffuse degenerative articular disease are generally treated non-operatively. Non-operative management consists of activity modification, maintenance of ideal body weight, over the counter non-steroidal anti-inflammatory medications, physical therapy, and occasionally intra-articular corticosteroid or viscosupplementation injections.[1,12] Operative treatment ranges from simple arthroscopic lavage and debridement to marrow stimulation techniques (microfracture and subchondral drilling), cell based cartilage repair (autologous chondrocyte implantation) and whole tissue transfer (osteochondral autograft transfer and osteochondral allograft transplantation).

Although there are several operative treatment options for the treatment of articular pathology, each method has inherent limitations.[11] For instance, marrow stimulation results in a hyaline-like fibrocartilage repair surface, which has been shown to be physiologically and biomechanically inferior to native hyaline cartilage.[6,7] Osteochondral autograft transfer (OAT) is limited by donor site morbidity and the availability of autologous grafts from areas of lower contact pressures on the weight-bearing articular surfaces of the knee.[13-15] Debridement, marrow stimulation techniques, and OAT have been reported to be ineffective or impractical for lesions >2 cm^2.[16-18] Staged cell-based cartilage repair such as autologous chondrocyte implantation (ACI) remains a viable option for large defects of the knee in young, active patients, though it necessitates two separate procedures and a prolonged recovery.

Osteochondral allograft (OCA) transplantation, however, is a single-stage technique that utilizes full thickness, viable hyaline cartilage, avoids donor site morbidity, permits resurfacing of large defects, and potentially yields a more natural, matching contour of the native recipient surface anatomy.[19] Research conducted utilizing OCA transplantation for knee chondral repair demonstrated improved patient reported outcome scores (compared to pre-surgical scores)[19-22] and graft survival rates of between 79% and 100% at a mean follow-up of two to four years,[19-21,36] 78% at 10 years,[36] approximately 73% at 15 years,[22,36] and 67% at 20 years.[36] OCA transplantation has also been shown to be preferable in the setting of unshouldered lesions, extensive subchondral edema, or extensive bone loss that requires restoration.[23,24]

Following OCA transplantation, strict adherence to a rehabilitation protocol is critical to promote full recovery. The presented rehabilitation protocol is informed by the existing literature and incorporates current rehabilitation principles, the science of osteochondral incorporation, and adaptations based on an individual's readiness to progress through subsequent phases. The purpose of this clinical commentary is to discuss the diagnosis, surgical management, and post-operative rehabilitation following OCA transplantation and to assist the physical therapist in returning athletes to full sports participation.

CLINICAL PRESENTATION

Among athletes, the mean age of patients with knee chondral injuries has been reported to be 33 years (range 26-47).[25] Males (62%) have been reported to be affected more commonly than females (38%).[26] The patellofemoral joint is reported to be affected most frequently (37%), of which patellar defects have been reported to be more common than trochlear (64% and 36%, respectively) followed by the femoral condyles (35% overall; 68% medial vs. 32% lateral), and tibial plateau (25%).[25]

Patients with knee chondral injuries may report insidious or traumatic onset of symptoms. They often experience pain with weight bearing, swelling exacerbated by activity, limping, and/or feelings of instability.[10] Patients may also report mechanical symptoms such as locking or catching, which may be indicative of a chondral flap tear, a large defect, or a loose intra-articular body. Prior non-operative and operative management should also be noted.

A thorough knee examination should include assessment of tenderness to palpation, passive and active motion, strength, ligamentous stability, lower extremity alignment and gait. The presence of knee effusion, quadriceps inhibition, and restricted passive and active motion may suggest intra-articular pathology. Tenderness to palpation at the joint line or just above may be indicative of a meniscal injury or chondral lesion of the femoral condyle.[27] Patellar apprehension, patellofemoral crepitus, or a positive patellar grind test may raise suspicion for a patellofemoral defect. Atrophy of the quadriceps, especially the vastus medialis, is often indicative of a chronic injury.[27]

In addition to examination of the involved knee, a complete examination of the patient's lower extremity and core is necessary to assess for concomitant strength and flexibility deficits, as well as gait dysfunction. If tolerated by the patient, pre-operative functional testing to develop a baseline for future testing may also be performed. Multiple functional tests and maneuvers exist of varying levels of complexity. The Vail Sport Test™ has been found to have excellent intra-rater reliability and includes the following individual components: single leg squats, lateral bounding, forward and backward jogging.[28]

The patient history and physical exam findings associated with knee chondral injury are often non-specific and may also be found in patients with patellar instability, meniscal tears, cruciate ligament injuries, and other intra-articular pathology. Therefore, it is important to keep a broad differential and proceed with diagnostic imaging.

IMAGING

Radiographic evaluation should include bilateral weight bearing anteroposterior, lateral, 45-degree flexion posteroanterior, and patellofemoral (sunrise) views of the knee.[7] Sizing markers should be used to facilitate allograft size matching to the recipient site.[29] Standing long axis views of the lower extremities should also be obtained to assess the mechanical axis and determine if corrective osteotomy is needed.[9,10,29] The mechanical axis should fall centrally between the tibial eminences, as genu varum or valgum malalignment is thought to cause compartment overload and premature graft failure.[1,9,30,31]

High-resolution magnetic resonance imaging (MRI) of the knee is a reliable means with which to evaluate articular cartilage defects.[32] The area of the lesion may be measured on MRI by determining the largest defect diameter on two orthogonal views and multiplying them.[1] However, MRI alone has been shown to underestimate the mean defect area by up to 60%.[33,34] Cartilage-specific MRI sequences including T1rho (also referred to as T1ρ or "spin lock") and T2 mapping permit a more detailed evaluation of a lesion's size and location.[10] MRI also enables evaluation for concomitant pathology, such as ligamentous or meniscal injury, and identification of subchondral edema. Computed tomography (CT) arthrography may also be useful in patients unable to undergo MRI or after failed prior cartilage repair to assess changes in the subchondral bone.[9]

SURGICAL INDICATIONS

OCA transplantation is indicated for primary surgical management of large (>2-3 cm^2), full thickness (grade 3 or 4) chondral or osteochondral lesions of the femoral condyles,[29] as well as second-line treatment of patellofemoral[35] and tibial defects in symptomatic patients refractory to nonsurgical treatment.[1,8-10,24,36] Idiopathic and posttraumatic lesions, as well as defects associated with osteochondritis dissecans (OCD), osteonecrosis, and failed prior cartilage repair may be treated with OCA transplantation.[8-10]

Contraindications include current tobacco use, body mass index (BMI) > 35 kg/m^2, inflammatory conditions, diffuse degenerative articular changes, or uncorrected knee pathology such as knee malalignment, abnormal patellar tracking, meniscal deficiency, or ligamentous insufficiency.[8,9]

Articular or peri-articular pathology should be corrected prior to, or at the time of, OCA transplantation. To prevent overload of the diseased compartment, genu varum may be corrected with medial high tibial opening wedge osteotomy; genu valgum may be corrected with a lateral distal femoral opening wedge osteotomy.[1,8,9] Meniscal transplantation may be considered for meniscal deficiency, and a tibial tubercle osteotomy or patellar retinacular procedure are options to address pathologic patellar tracking.[1,8,9]

SURGICAL MANAGEMENT

OCA transplantation is performed under general anesthesia with the patient in the supine position. Once satisfactory anesthesia is administered, a thorough examination of the knee is completed. If planning to use platelet-rich plasma (PRP) or other biologic adjunct, blood should be drawn from the iliac crest or other site for later use.[35] A well-padded thigh tourniquet is applied, and diagnostic arthroscopy may be performed.

Depending on the location of the lesion, a medial or lateral parapatellar arthrotomy is carried out. The size of the chondral defect is measured using templates of various sizes, matching the size that will completely cover the defect. A guide pin is placed in the center of the defect and the defect edges are scored. The defect is reamed to create a socket for the OCA transfer, while irrigation is applied to prevent heat necrosis of the adjacent articular cartilage and subchondral bone. Reaming is continued until bleeding, healthy bone is encountered with care taken not to exceed a maximum of 7 or 8 mm of overall bone depth.[29] The reamed defect is then measured carefully to ensure proper donor plug trimming.

The fresh (15-28 days) allograft is warmed by soaking it in room temperature saline. Once warmed, the allograft specimen is secured in an allograft workstation and the osteochondral donor plug is harvested with the use of a coring reamer (Figure 1). Again, irrigation is used to prevent heat necrosis. The plug is trimmed to match the desired depth and diameter of the defect.

Preparing for implantation, the donor plug is cleansed with saline using pulsed lavage to remove

Figure 1. *The allograft specimen is secured in an allograft workstation and the osteochondral donor plug is harvested.*

any remaining bone marrow elements from the subchondral bone. This is thought to minimize the chance of immune reaction by the recipient.[10,29] If blood was drawn to use as a biologic adjunct, the graft may be soaked in platelet-rich plasma (PRP) or other biologic medium.[35] The bone plug is then inserted via a "press fit" technique into the recipient socket to match the exact height of the surrounding articular cartilage. If the fit is satisfactory, the knee is copiously irrigated and the wound is closed in a layered fashion.

REHABILITATION

The post-operative rehabilitation protocol for osteochondral allograft transplantation utilized at the senior authors' (MTP, RFL) institution emphasizes early motion with a supervised rehabilitation program commencing immediately post-operatively (See Appendix 1).[19] Progression of the protocol should be performed under careful supervision by the rehabilitation team, with attention to proper progression. The number of repetitions and sets performed for each exercise, as well as the amount of time holding for each stretch should be tailored to the individual. General guidelines are provided in Appendix 1. Improper phase progression may often present with persistent or recurrent pain and/or swelling; if this occurs, the patient should rest, decrease the number of repetitions and sets performed, and slowly progress as tolerated. The overall principles guiding OCA transplantation rehabilitation include protection of the knee joint from load and sheer forces, with the safe and step-wise return to weight bearing activities and sport.

Progression of Rehabilitation Phases

Phase I: Early Recovery (Weeks 0 to 8)

Early goals include pain and effusion reduction. The graft must be protected from load and shear forces, and the patient should remain non–weight bearing for the first eight weeks. Immediate range of motion is permitted, with emphasis on attaining full knee extension. Passive and active knee range of motion is not restricted, except for patients who have undergone OCA transplantation for a focal patellar osteochondral lesion; these patients remain limited to 90 degrees of knee flexion during the first two weeks after surgery to protect the allograft. Scar and adhesions along the incision site or arthroscopy portal sites may lead to loss of patellar mobility, and immediate patellar mobilization in all directions is recommended. These mobilization exercises should be a component of the patient's home therapy program, performed for five minutes, three to five times every day.[37] Additionally, in the early stage of recovery is restoration of quadriceps control: quadriceps setting exercises, terminal knee extensions and straight-leg raises with the patient wearing a knee immobilizer (or locked hinged knee brace) should be performed four times daily.[37]

The proposed benefits of cryotherapy are well established and include edema control, local vasoconstriction and pain reduction.[38] Multiple cryotherapy modalities, including crushed ice or cold packs, have also been shown to be effective for short-term pain reduction.[39] A prospective randomized study analyzed an active compression cold therapy system following anterior cruciate ligament reconstruction and reported significant increased range of motion and functional knee scores compared to cold therapy alone.[40] In the authors' treatment protocol, patients are prescribed an active compression cold therapy device (Game Ready®, Concord, Georgia, U.S.A.) on low compression for thirty minutes followed by sixty minutes off to allow for skin temperature recovery. This cycle repeats itself at least four times each day.

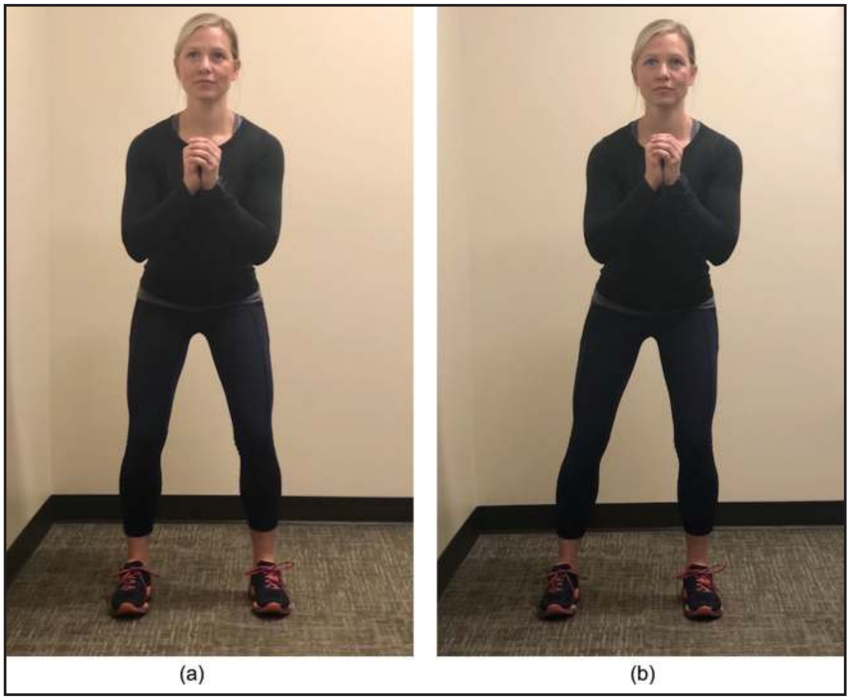
Phase II: Weeks 8 to 12

The next phase of rehabilitation focuses on gait normalization and early strengthening (Appendix 1). Full active and passive motion should be achieved by initiation of this phase and is obtained through both manual therapy and independent patient exercises, such as supine wall slides, supine active knee flexion, quad sets and prone knee extension with gravity. Patients may begin weaning from crutches, progress weight bearing and initiate a series of balance exercises (Figures 2a, 2b; 3a, 3b). A step-wise advancement of weight bearing is implemented to incrementally increase load to the joint with care to avoid a rapid increase in stress to the graft site. A persistent or recurrent knee effusion may inhibit quadriceps firing and lead to a gait abnormality,[41] and a limp or gait abnormality is a contraindication to advancement of rehabilitation phases. Pool walking, and assistive ambulation systems or treadmills, provide a useful option to advance weight bearing tolerance in a controlled environment. Once full weight bearing is accomplished, restoration of a normal gait pattern is emphasized.

More recent attention[40] has been given to the significant emotional disturbance, anxiety and depression associated with significant knee injuries in athletes, which may be associated with loss of their athletic identity. Evidence for the use of aerobic exercise multiple times per week to lower these symptoms has been demonstrated.[42] Cardiovascular fitness training may be introduced as early as week 8 postoperatively with no resistance biking and aqua jogging. Biking with resistance and swimming with fins may begin at post-operative week 10.

Phase III and Phase IV: Weeks 12 to 20

Phases III and IV emphasize the increase in functional strength of the lower extremity with weight training and advancing cardiovascular fitness exercises. The progression of these phases is outlined in Appendix 1. Therapists should implement a schedule of training variables, including increasing load, sets and repetitions (periodization) to maximize training adaptations and to prevent overtraining.[43] Combined balance and strength exercises are performed (Figures 3 through 6). Fully weight bearing cardiovascular exercises, including inclined treadmill walking and the elliptical trainer begin 16



Figures 2a and 2b. *Weight shifts may be performed as patients progress to full weight bearing. Begin by standing with feet hip-width apart. Initially, weight is distributed more to the non-operative leg with progression towards equal weight distribution to both feet (2a). Progress to shifting weight to one side and holding for 30 seconds (2b). Return to the starting position and repeat on the opposite side.*

Figures 3a and 3b. *Single leg stands may be performed to increase balance. Begin by standing with feet hip-width apart. Initially, weight is equally distributed on both legs. Lift one leg off the floor and balance in the upright position for 30 seconds (3a). Return to the standing position and switch sides. As balance and strength improve, the elevated leg may extend back as the torso bends forward (3b). A walking stick or ski pole may be used initially to assist with balance.*

Figure 4. *Reverse lunge with static hold. Stand with feet hip to shoulder-width apart. Take a step back with one leg while keeping the torso erect and bending both knees. Hold for an increasing amount of time as strength improves. Return to starting stance; repeat and alternate sides.*

weeks post-operatively. As with earlier phases, an increase in swelling or pain indicates inappropriate phase progression.

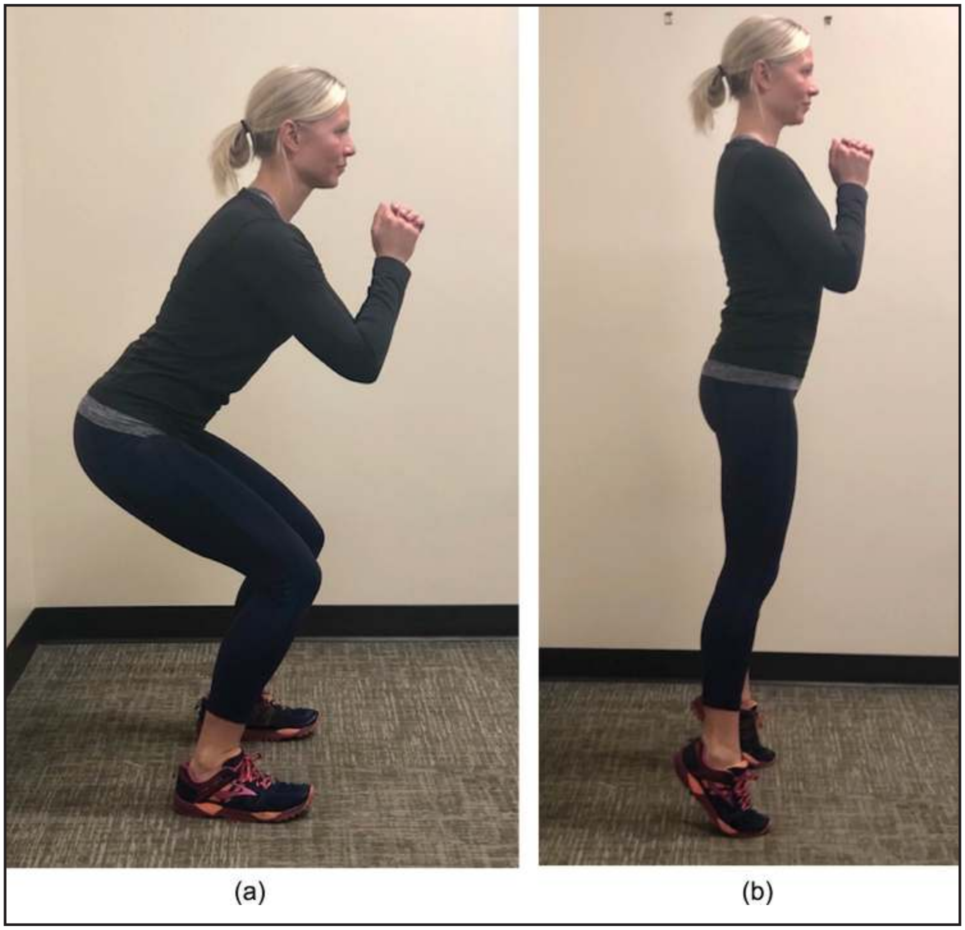
Phase V: Week 20+

Low-impact activities are recommended for the first 12 months to allow complete healing and incorporation of the graft. All patients are advised to perform low-impact activities and avoid high-impact activities as much as possible. Upon achievement of full lower extremity strength, range of motion and proprioception, readiness for return to activity may be determined with functional sport testing. A simple assessment of adequate balance and control during performance of a single-leg squat to 90-degrees of flexion is a reliable test to evaluate frontal plane motion of the knee.[44] When adequate balance and control is demonstrated, a progression of running, cutting and agility skills may commence. Principles of safe progression are essential, including using flat surfaces before incline or decline, even surfaces used followed by uneven surfaces, straight line maneuvers prior to cutting, and simple followed by complex agility tasks. As throughout the protocol, attention is paid to observe for a return of pain and/or 242 swelling, which may indicate improper advancement.

Further readiness testing may be performed on a sport-specific basis. The Vail Sport Test™ has excellent intra-rater reliability when used as a measure of physical performance following anterior cruciate ligament reconstruction. The test variables, including single leg squats, lateral bounding, as well as forward and backward jogging, provide useful information in the determination of readiness to return to play.[28] Sport-specific exercises may also be assessed to further delineate readiness. LaPrade[45] and colleagues reported improved patient-reported outcomes following OCA transplantation, with a survival rate of 78.8% at 10 years. Those with worse survival rates included revision cases, patellar chondral lesions and bipolar lesions, indicating proper patient selection is key to improving results.

SUMMARY

Chondral injuries of the knee are common among young, active patients presenting with knee pain, swelling, and/or mechanical symptoms. These injuries have limited healing potential due to the avascular nature of hyaline cartilage. While several treatment options exist, OCA transplantation for the knee has been used successfully in primary management of large chondral or osteochondral defects, and salvage of previously failed cartilage repair. OCA transplantation potentially yields a natural, matching contour of the native recipient surface anatomy and transplants mature, viable hyaline cartilage to the affected defect. Following OCA transplantation, strict compliance with a rehabilitation protocol is essential to enable optimal recovery. The outlined rehabilitation protocol is informed by the existing literature and incorporates current rehabilitation principles, the science of osteochondral incorporation, and adaptations based on an individual's readiness to progress through progressive phases. The rehabilitation protocol provides a safe and effective stepwise approach to return patients to their preferred sport or activity.



Figures 5a and 5b. *Squat to calf raise. Stand with feet hip to shoulder-width apart. Begin with traditional body-weight squat. As emerge from the squatting position, progress to a standing calf raise.*

Figures 6a and 6b. *Double leg bridges with heels on ball with added hamstring curl. To perform double leg bridges with heels on ball (6a), lie supine and place both heels on a medicine ball. Lift hips off the floor and hold with back straight. Return to resting position. Add a hamstring curl (6b) by flexing the knees as heels roll the ball towards the glutes with hips off the floor and back straight. Extend the knees as heels roll the ball back to starting position.*

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Appendix 1. *Osteochondral Allograft Transplantation Protocol.*

Phase I	
0 to 8 weeks after surgery	
	Precautions: • Range of motion as tolerated* • Hinged knee brace x 8 weeks • Non-weight bearing x 8 weeks
	Goals: • Regain full knee range of motion by week 6 • Protect knee joint from load and shear forces
	Therapeutic Exercises: • Active and passive knee flexion/extension (seated) • Patella mobilization • Extension mobilization • Quadriceps sets (begin with 2 sets of 10) • Straight leg raises (begin with 2 sets of 10) • Sidelying hip abduction and adduction (begin with 2 sets of 10) • Hamstrings sets (begin with 2 sets of 10) • Ankle pumps (begin with 2 sets of 10) Low load prolonged stretching • Sit and reach towel stretch (hamstrings)

*Patients status post osteochondral allograft transplantation for a focal patella lesion are restricted from 0 to 90 degrees of motion for weeks 0 to 2 post-operatively.

Phase II

8 to 12 weeks after surgery	
	Precautions: • Week 8: Begin weight bearing progression (Figures 2a and 2b); wean from crutches • Week 8: Discontinue hinged knee brace
	Goals: • Full, pain free range of motion • Normalize gait
	Therapeutic Exercises • Gait training / wean from crutches • Toe and heel raises (begin with 2 sets of 10) • Straight leg raises (continued) • Sidelying hip abduction and adduction (continued) • Balance series (Figures 3a and 3b) Cardiovascular Exercises (Weeks 8-10): • Bike with both legs (no resistance) • Aqua jogging Cardiovascular Exercises (Weeks 10-12): • Bike with both legs (with resistance) • Swim with fins Low load prolonged stretching • Hamstrings towel or doorway stretch • Standing calf stretch (with knee flexion and extension)

Appendix 1. *Osteochondral Allograft Transplantation Protocol. (continued)*

Phase III	
12 to 16 weeks after surgery	
	Precautions: • None
	Goals: • Increase functional strength of lower extremity
	Therapeutic Exercises • Squats to 90 degrees (begin with 2 sets of 5) • Double leg bridges • Reverse lunge with static hold (Figure 4; begin with 2 sets of 5) • Begin elastic resistance exercise series • Balance series progression (Figures 5a and 5b) Cardiovascular Exercises • Bike with both legs (with resistance - continued) • Swimming with fins and/or aqua jogging (continued) Low load prolonged stretching • Quadriceps and hip flexor stretching • Hamstrings towel or doorway stretch (continued) • Standing calf stretch (with knee flexion and extension – continued)

Phase IV

16 to 20 weeks after surgery	
	Precautions: • None
	Goals: • Increase lower extremity strength • Increase cardiovascular fitness
	Therapeutic Exercises • Balance series progression (continued) • Squats to 90 degrees – add weight to upper extremity • Double leg bridges with heels on ball (Figure 6a); add hamstring curl as strength allows (Figure 6b) • Reverse lunge with static hold (continued) • Cord exercise series (continued) Cardiovascular Exercises • Bike with both legs (with resistance - continued) • Treadmill walk – progress to 7% incline • Elliptical trainer • Swimming with fins and/or aqua jogging (continued) Low load prolonged stretching • Hamstrings towel or doorway stretch (continued) • Quadriceps and hip flexor stretching (continued) • Standing calf stretch (with knee flexion and extension - continued)

Appendix 1. *Osteochondral Allograft Transplantation Protocol. (continued)*

Phase V	
20+ weeks after surgery	
	Precautions: • None
	Goals: • Initiate return to sport exercises
	Therapeutic Exercises • Balance squats • Double leg bridges with heels on ball with hamstring curl (continued) • Reverse lunges (continued) • Single leg deadlift • Leg press • Sport-specific exercises Cardiovascular Exercises • Bike with both legs (with resistance - continued) • Treadmill walk – progress to 7% incline • Swimming with fins and/or aqua jogging (continued) Low load prolonged stretching • Hamstrings towel or doorway stretch (continued) • Quadriceps and hip flexor stretching (continued) • Standing calf stretch (with knee flexion and extension - continued)
	Activities of Daily Living (ADL): • Full ADLs without restriction • Return to golf, outdoor biking, hiking and snowshoeing at 26-weeks post-operatively