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Rehabilitation following osteochondral injury to the knee

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Abstract Articular cartilage injuries of the knee can be debilitating if not treated properly. Once an articular cartilage injury is sustained there are a variety of surgical interventions depending on the severity of the injury. The most common of these procedures are: osteochondral autograft transplantation (OATS), autologous chondrocyte implantation (ACI) and microfracture. The rehabilitation outlined in this article is specific to the exact surgical procedure performed and the location in the knee. The outcomes of these procedures are also discussed.

Keywords Knee · Rehabilitation · Articular cartilage · Osteochondral Autograft Transplantation (OATS) · Autologous Chondrocyte Implantation (ACI) · Microfracture

Introduction

Articular cartilage pathology can affect several joints in the human body though it deserves special attention in the lower extremity. Of the weight bearing joints, the knee is particularly vulnerable to articular cartilage lesions given its role in the kinetic chain, unique biomechanical design, and the demands it is subjected to during activities of daily living (ADL) and sport. Consensus exists that ulcerated cartilage poses a significant challenge to the orthopedic surgeon and physical therapist largely because without intervention articular cartilage lesions have minimal to no potential of healing. Furthermore, articular cartilage lesions are highly prevalent according to a retrospective review of over 31,000 knee arthroscopic procedures, Curl et al. found a prevalence of 63% of chondral lesions with a mean of 2.7 lesions per knee [1]. Aroen and colleagues demonstrated in 993 consecutive knee arthroscopies, 66% of patients possessed articular cartilage pathology with 11% of these knees exhibiting full thickness articular cartilage lesions [2]. A prospective study of 1000 consecutive arthroscopies showed chondral or osteochondral lesions of any type in 61% of the patients, whereas focal chondral or osteochondral defects were found in 19% [3]. In other studies the prevalence of articular lesions has been reported to range from 22% to 50% [4, 5].

The components of normal articular cartilage include articular cartilage cells (chondrocytes), collagen, ground substance, and water. Each of these components is responsible for the ultimate structure found within articular cartilage. Chondrocytes constitute approximately 5% of the weight of articular cartilage and are responsible for the daily maintenance of collagen and ground substance. Chondrocytes increase their production of collagen and ground substance when pathology occurs, but the number of chondrocytes is limited given their inability to reproduce.

Collagen is the most common fibrous structure found within articular cartilage and serves to provide mechanical stability (strength and stiffness) to the articular cartilage matrix. Collagen is produced by chondrocytes and when the number of chondrocytes is reduced there is an initial decrease in the number of collagen fibers. Type II, Type IX, and Type XI collagen are most numerous in articular cartilage. The nasal septum, sternal cartilage, and the inner

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regions of the intervertebral discs and meniscus also contain Type II collagen.

The primary ground substance in articular cartilage is a proteoglycan or glycosaminoglycan (GAG). GAGs provide articular cartilage with an elastic quality due to the large amount of water contained within this structure. Because chondrocytes produce ground substance, the amount of ground substance is ultimately limited to the number of chondrocytes. However, chondrocytes may increase their production of ground substance in the presence of pathology.

A complete understanding of articular cartilage is limited without recognizing that water is the most abundant component found within this structure. Water is primarily an extracellular substance ranging from 65% to 80% of the total weight within various zones of articular cartilage. Due to the extracellular nature of water it is moveable within articular cartilage. When a compressive load is applied to articular cartilage up to 70% of water is moveable. Therefore the flexibility of articular cartilage during compressive loading is primarily due to the movement of water.

Focal chondral and osteochondral defects of loading surfaces often cause symptoms such as pain, swelling, catching, and instability. Of even greater concern is the fact that such lesions may result in early degenerative changes and decreased function. Various surgical techniques have been described in the literature to address articular cartilage pathology and include debridement, drilling of the defect, microfracture, and abrasion arthroplasty. Although these techniques have afforded several patients improved function, they fail to restore the biomechanical characteristics of the native hyaline cartilage. In the past two decades the development of reconstructive procedures has been designed to restore hyaline or hyaline like cartilage. The most common of these procedures are: osteochondral autograft transplantation (OATS), autologous chondrocyte implantation (ACI) and microfracture.

Microfracture

Marrow stimulation techniques such as drilling of the subchondral bone to allow the hole to be filled with fibrocartilage have been described previously by Pridie for the treatment of osteoarthritis of the knee [6]. Microfracture, which has been used arthroscopically to treat chondral defects, was developed and first used in the 1980's by Steadman [7]. This method was developed to provide an appropriate environment to enhance the body's own healing capacities for tissue repair. For the orthopedic surgeon, microfracture is often used as a first line of treatment because the procedure is not as technical as others, patient morbidity is low, and it is relatively cost effective. It has been shown to be an effective treatment for lesions smaller that 4 cm^2 and in patients under the age of forty [8–10]. Additionally, if microfracture is unsuccessful, further surgical procedures can be performed without concern for excess damage being done from prior surgery.

Microfracture-post-operative rehabilitation guidelines

The time period for chondral defect healing is not well established in humans, so there is typically a restricted or non-weight bearing phase to protect the repair tissue. However, chondral defect healing after microfracture has been investigated in primates. Gill and colleagues [11] studied a total of 12 primates who received microfracture to the medial and lateral femoral condyles and trochlear groove of each knee. Results demonstrated limited repair of the chondral tissue at 6 weeks with resorption of subchondral bone. By 12 weeks, the bone demonstrated improved bone repair and hyaline-like cartilage that was more mature [11]. These findings suggest that restrictions in weight bearing and protection of the defect site may be warranted for greater than six weeks to allow the tissue repair to adapt to increased stress. Following microfracture surgery, the rehabilitation program proceeds in accordance with the anatomic location and size of the chondral defect. Other factors such as age, body mass index (BMI), and activity level must also be considered when developing a treatment plan. Because of this, two different guidelines have been developed to address lesions for both the femoral condyles and patellofemoral region.

Rehabilitation for defects on the condyles of the femur or tibial plateau

Phase I: 0–8 weeks

The initial goals of phase I include protecting the site of repair, restoring normal quadriceps function and patellar mobility, and decreasing swelling of the joint. Given that the femoral condyles are weight-bearing surfaces, restrictions are placed upon the amount of weight a patient is allowed to place upon the involved lower extremity. In most cases touchdown weight bearing with assistance of crutches is allowed during the first 6–8 weeks though this could change depending upon the size and location of the lesion. If the lesion is small, weight acceptance may be accelerated. This is outlined in Table 1. Bracing of the knee is not typically performed with femoral condyle or tibial plateau lesions.

Immediately after surgery the patient is placed in a CPM machine for 6–8 h per day. Range of motion (ROM) is started from either 0–60° or 30–70° and gradually progressed by 10–20° based upon patient tolerance until reaching full passive ROM [12]. The use of CPM after microfracture

Table 1 Rehabilitation considerations following microfracture

Microfracture	
Assistive Devices	Crutches for all lesions. Bracing not typically performed except for patellar/trochlear lesions in which case orthosis prescribed initial 8 weeks with ROM restricted 0–30°.
Weight bearing	Condylar lesions: TTWB with crutches during initial 6–8 weeks then progressed to WBAT
	Patellar/Trochlear lesions: PWB progressed to WBAT after 2 weeks in knee brace
CPM	Condylar lesions: Immediately 6–8 h/day, starting from 0–60 or 30–70° and advancing 10–20°/day until reaching full PROM
	Patellar/Trochlear lesions: Per above but starting 0–50°
	*If no CPM then perform wall slides - 500reps, 3x/day
ROM	Unloaded PROM exercises in ranges tolerated initially starting in CPM per above guidelines
Strengthening	Weeks 0–8: QS, SLRs-4way, wall slides, ankle pumps, core stability training. Stationary bike with no resistance can begin at 2 weeks.
	Weeks 8–12: Gait training initially emphasized. Treadmill, elliptical, bike with resistance, interval pool workouts in waist high water allowed when patient is walking independently, carpet drags (high repetitions with good eccentric control)
	Weeks 12–16: 4 way hip PREs in standing, sidestepping and forward/backward walking, cardiovascular program advanced to 75%
	Weeks 16+: Functional sporting loads, moderate weight training i.e. leg press 0–90°, leg curls/extensions, squats, lunges (maintaining good frontal plane control), light agility work. Cutting or pivoting is restricted until 4–6 months out of surgery.

has demonstrated improvements in cartilage lesion grades in patients with full thickness chondral defects [13]. A total of 77 patients participated in a study by Rodrigo and colleagues, with 46 using CPM and 31 who did not. The average duration for CPM use was 7.83 weeks. Improvements in articular cartilage in those patients who used CPM was significantly greater (P=.003) than those without CPM when measured using second look arthroscopy. Additionally, these improvements were the same regardless of patient age or lesion location [13].

Therapeutic exercises in phase one include quad sets, straight leg raises (SLRs) in all four directions, wall slides, ankle pumps, and core stabilization training. Emphasis is placed upon patellar mobilizations in the medial, lateral, superior, and inferior directions to decrease the risk of arthrofibrosis. The patient is also taught self-mobilizations to be performed at home three to four times per day. Cryotherapy is used for pain and inflammation and is continued until signs and symptoms are under control. After 1–2 weeks, stationary biking with no resistance and aquatic exercises in deep water are initiated. The goals of phase one are to decrease swelling, increase ROM, protect the site of healing, and improve quadriceps function.

Phase II: 8–12 weeks

As the patient completes phase one and enters into phase two, gait training is emphasized initially. Weight bearing status is progressed as the patient weans off the crutches and is allowed to bear weight as tolerated. Instructions for correct gait mechanics are given to the patient and reiterated as the normal gait pattern is restored. More aggressive activities such as incline treadmill walking, interval pool workouts, elliptical, and bike with resistance are acceptable once gait is normalized and pain free. Exercises in this phase, shift from early protection of the surgical site to concentrating on muscle endurance of the quadriceps, hamstrings, gastrocnemius-soleus complex, and gluteal muscles while continuing to focus on core stability. Patients are instructed to perform high repetitions of these muscle groups using good eccentric control with each exercise in order to protect the site. If the patient is fatigued, the muscles are less likely to offer protection and exercise in this case could cause damage. As the muscle endurance base is established, strength gains can be made in later phases. The goals of this phase include protecting the surgical site, increasing muscle endurance and proximal stability, reestablishing proprioception and kinesthesia of the knee and lower extremity. While the site is ready to accept greater loads in this phase, overstressing the joint can cause an inflammatory response and hinder the rehabilitation progression.

Phase III: 12–16 weeks

In the third phase of rehabilitation the cardiovascular portion of the rehabilitation is intensified over the ensuing 4 week period with the bike and elliptical while calling attention to the importance of low impact joint loading. Agility exercises are initiated on soft surfaces while focusing on controlling the forces going through the knee by using correct form and using the muscles for shock absorption. The key focus of this phase involves teaching the patient to protect the joint surface by eccentrically loading the muscles during functional activities. This first includes instructing the patient how to control the knee in all three cardinal planes of motion. It has been suggested decreased core and hip strength have been implicated as factors contributing to lower extremity alignment during functional activities. Weakness of the hip extensors can lead to quadriceps overuse and increased compression and shearing at the knee joint. When weakness in the core and hip musculature exists, lower extremity injuries can occur. Athletes who are able to demonstrate good hip abduction and external rotation strength are less likely to suffer a lower extremity injury. Rehabilitation of the knee should include a component of hip and core strengthening throughout each phase.

Phase IV: 16 weeks to return to sport

At this point the microfracture is strong and agility exercises can safely be advanced. Exercises are structured such that functional sport loads are applied to the joint in preparation for return to sport. Based upon the performance demands of the sport, rehabilitation at this stage should attempt to recreate an environment similar to what the athlete will encounter on the field of play. This is the only way to know whether if the patient is physically and mentally ready to return to full function. Modified weight training is also begun at this point. Leg press above 90°, leg curls, short arc leg extensions, and squats can be performed with high repetitions and low weights if the patient employs good control with a neutral spine. Agility drills are progressed to full speed or 100% throughout this phase. Soft surfaces are still encouraged while reminding the patient to absorb the forces through the muscles. Outdoor activities such as biking and golfing are also performed during this phase. Return to running, skiing, basketball, soccer, and football are considered between 6–9 months. Typically, sports that demand jumping, cutting, or twisting may require a longer rehabilitation period prior to full return. Determination of readiness for return to play, however, is dependent upon the size and location of the lesion, the healing of the microfracture site, and the ability of the patient to efficiently use the muscles to absorb forces encountered during these activities.

Rehabilitation for defects on the trochlear groove or patella

There are a few differences in rehabilitation of defects on the trochlear groove or patella as compared to tibiofemoral lesions. After surgery, those patients with defects on the trochlear groove or patella are placed in a brace with ROM restricted from 0° to 30° [12]. The brace is worn for the initial 8 weeks to prevent the median ridge of the patella from engaging the trochlear groove and potentially causing compression and shear forces to the site of repair during knee flexion. At 8 weeks, the patient is gradually weaned from the brace. Partial weight bearing on the affected extremity is allowed after surgery and progressed to weight bearing as tolerated (WBAT) after 2 weeks within the brace. Immediately after surgery, CPM is started from 0° to 50° and progressed according to the same parameters for tibiofemoral lesions.

For most patients, full passive ROM after surgery is allowed unless there are multiple defects, the size of the defect is significant, or “kissing lesions” are present. In this case, ROM limits are adjusted accordingly. Apart from bracing, weight bearing, and ROM restrictions, the initial 8 weeks of the rehabilitation process follows the same guidelines as that of the tibiofemoral lesion. During the remainder of the rehabilitation process, careful attention is given to the joint angles encountered during strengthening exercises. In order to prevent joint compression and/or shearing forces at the repair site, the angle at which the patella engages the trochlear groove is avoided for the first 4–6 months during strengthening exercises. Otherwise, progression of rehabilitation follows the same standards as described for microfracture in the femur and tibia.

Microfracture outcomes have shown decreased pain levels, increased activities of daily living (ADL) and work, and sport capabilities [14, 15, 28, 34]. In a case series of patients with full-thickness traumatic defects of the knee treated with microfracture, a decrease in pain and improvement in function in 95% of the population was seen up to 17 years postoperatively [14]. The rehabilitation procedure followed the guidelines described earlier in this manuscript. Significant improvements in Lysholm scores (preoperatively, 59; postoperatively, 89) and Tegner scale (preoperatively, 3;postoperatively, 6) scores were seen. Additionally, there was a 77% return rate of the elite athletic population. Overall, age was found to be a predictor of improvement in function, with those patients under the age of 45 showing greater improvement. Patient satisfaction scores have also been measured in patients following microfracture. Subjective measures such as pain, swelling, difficulty walking, difficulty going up stairs, and activities of daily living all showed significant improvement when compared to before surgery [14]. When the microfracture procedure was performed in a group of athletes improvements in function were seen. Lysholm scores improved from 56.8 to 87.2 after surgery while Tegner scores rose from 3.2 to 6 at the two-year follow-up. The athletic population showed an 80% improvement in sports activities during the initial 2 years, but this gradually declined to 55% at 5 years. The authors attributed this decrease to the natural decline in one’s ability to perform at a high level with age as well as the possibility that the fibrocartilaginous repair tissue has less resilience and may deteriorate over time [15].

Osteochondral autograft transplantation (OATS)

Yamashita et al. first described OATS as a case report in 1985 [16]. OATS, which has also been referred to as mosaicplasty, involves the transplantation of bone plugs with overlying articular cartilage, which are harvested from non-weight-bearing areas of the knee to restore damaged articular cartilage. OATS involves the use of several bone plugs of similar or varying sizes. This technique, however, is limited by the amount of donor tissue available. The ideal indications for OATS include symptomatic, distal femoral condyle articular lesions with intact menisci and tibial cartilage in a non-degenerative joint with proper mechanical alignment. While reports of treating large lesions with this technique exist, the ideal lesion is between 1 and 4 cm^2 and/or in the setting of bone loss [17, 18]. Furthermore, lesions deeper than 10 mm are not amenable, since plugs usually are about 10–12 mm in depth [19]. The peripheral parts of both femoral condyles at the level of the patellofemoral joint can serve as donor sites. Notch area grafts are also usable but less favorable due to the concave hyaline cartilage surface.

OATS—post-operative rehabilitation guidelines

In contrast to marrow stimulation procedures (microfracture and chondroplasty), which result in fibrocartilaginous tissue, OATS aims to restore type II or hyaline cartilage. By attempting to recreate the native articular cartilage, the biomechanical strength and resiliency of the tissues should prevent early onset of degenerative changes. Exposing the knee joint to a controlled amount of force without over stressing the healing tissue is the guiding principle of post-operative rehabilitation. The lesion, the patient, and the surgery dictate the speed of rehabilitation. A more cautious progression is encouraged when numerous bone plugs have been harvested due to the possibility of joint incongruence.

The location of the surgery is critical to safeguard against deleterious forces early in the rehabilitation process. It is imperative for the physical therapist to appreciate the biomechanical implications of every movement and prescribed exercise during the rehabilitation process to engender a successful long-term outcome. In regards to the tibiofemoral joint, when the knee is in full extension, the distal aspects of the femoral condyles articulate with the tibia; as the knee flexes, the femoral condyles roll posterior and glide anterior causing the axis of rotation to shift posteriorly while a simultaneous anterior shearing force occurs. The articulation between the femoral condyles and tibial plateau is constant and most articular lesions involving the femoral condyle are engaged between 30°–70° of knee flexion. The rate of rehabilitation should also be slowed in the face of meniscal damage since tibiofemoral contact area decreases and stress increases. Of equal importance, is a thorough understanding of patellofemoral mechanics, the inferior aspect of the patella articulates with the trochlea at approximately 10°–20° of knee flexion. As the knee flexes, the contact area moves proximally on the patella and articulates with the odd facets at roughly 30° of flexion. The middle facet of the patellar articulates with the trochlea at 60° of knee flexion while the superior facets engage the femoral condyles. The contact area of the patellofemoral joint increases as the knee is progressively flexed, for example: when the knee is flexed from 30°–90°, the contact area increases from 2 cm^2 to 6 cm^2. Understanding the biomechanical principles of the knee is critical for sound exercise prescription particularly for OATS.

Following OATS strict non-weight-bearing is indicated for the initial 2 weeks following surgery since a 44% reduction in push-in and pullout strength has been documented one-week post-operatively [20]. Partial weight bearing is allowed between weeks two and four based on the lesion size and the number of transplanted bone plugs. Research in German shepherds has demonstrated that bone plugs are united and by 6 weeks full subchondral integration has occurred. Despite integration having occurred, a 63% decrease in graft stiffness has been noted at the sixth post-operative week [21]. Weight bearing is gradually progressed from week six to eight at which time full weight bearing can ensue, since fibrocartilage exists on the surface. Immediate weight bearing is permitted for patients with patellofemoral lesions with the patient using a drop lock knee orthosis and progressed to full weight bearing without the brace at the sixth to eighth post-operative week.

Rehabilitation progression

It has been hypothesized that prolonged immobilization and unloading can negatively impact healing articular cartilage. Controlled weight bearing and ROM is indicated to improve the mechanical properties of the healing tissue. There are several key factors to consider when designing a rehabilitation program related to OATS and mosaicplasty (Table 2). The location of the lesion is one factor. Lesions involving a weight-bearing region of the femoral condyle should be protected from compressive forces while lesions on the trochlea or retropatellar surfaces should be protected against shearing forces. Size, depth, and containment of the lesion (s) are also of great importance because some patients with larger, deeper, and more poorly contained lesions should be progressed slower during rehabilitation. This procedure provides an option for articular resurfacing of the femoral condyles for focal areas of chondral defects [22•].

Table 2 Rehabilitation considerations following OATS

Osteochondral Allograft Transplantation Surgery (OATS)		
Assistive Devices	Crutches and hinged knee orthosis locked in full extension for all lesions.	
Weight bearing	Partial weight bearing is started depending on the location, size, and condition of the recipient site. Two-crutch ambulation with partial weight bearing is allowed at 2 weeks when the site is located posteriorly, or the patellofemoral joint. When the recipient site is located antero-central partial weight bearing is allowed at 2 weeks for a small defect, at 3 weeks for a medium-sized defect, and at 4 weeks for a large defect. Full weight bearing is allowed by 6 to 10 weeks depending on condition [37]	
CPM	Immediate; perform 6–8 h/day starting 0–60° progressing 5–10°/day except for patellofemoral lesions >6 cm^2 then 0–40°	
	*If no CPM then perform wall slides - 500reps, 3x/day	
ROM	Condylar Lesions	Patellofemoral Lesions
	Week 2–90°	Week 3–90°
	Week 3–105°	Week 4–105°
	Week 4–115°	Week 6–120°
	Week 6–125°	
Strengthening	Weeks 0–6: QS, SLRs-4way, active knee extensions 90–40° for condylar lesions but not permitted for patellar/trochlear lesions.	
	Weeks 6–12: Condylar lesions: active knee extensions 0–90° mini-squats (0–60°) at 8 weeks, leg press at 10 weeks (0–90°). Patellar/Trochlear lesions: mini squats (0–45°) at 8 weeks, leg press at 10 weeks (0–60°), active knee extensions (0–30°) at 12 weeks.	
	Weeks 12–26: Leg press, unilateral step-ups, hip PREs, progress active knee extensions, advance stationary cycling, stair-master, elliptical. It is important not to overload the patellofemoral joint (donor site) by avoiding squatting and eccentric exercise against heavy resistance for 2–3 months [37]	
	Weeks 26–52+: Progress resistance as tolerated, impact loading customized to patient's needs, straight line running is started by 3 months, heavy labor and sports activity can begin after 6 months per physician clearance. Highly demanding sports such as soccer and tennis can be resumed by 8 to 12 months after operation [38•]	

Hangody et al. in 2008 reviewed their results on more than 1000 mosaicplasties, the breakdown included 789 implantations on the femoral condyles, 147 in the patellofemoral joint, and 31 on the tibial condyles. Most of the patients had surgery for a localized grade 3 or 4 lesion, and the remainder had surgery for an osteochondral defect. Follow-up demonstrated a good to excellent result in 92% of patients with a femoral condylar implant, 87% of tibial implantations, and 74% of patellofemoral implantations [23].

Jakob et al. retrospectively reviewed 100 patients at a mean of 2 years after surgery; it was shown 86% of patient had an increase in knee function. The patients that had a second-look arthroscopy, the implanted cartilage were graded as nearly normal, suggesting that the transplanted cartilage was of good overall quality [24]. In a recent study, Matsusue and colleagues used the OATs technique on 32 patients. Using the ICRS (International Cartilage Repair Society) Evaluation Form, arthroscopic findings and MRI results, it was shown that in 89% of the cases had of normal or nearly normal results [18]. In a prospective study, Maracci et al. evaluated the outcome of OATs for treatment of femoral condyle cartilage lesions in 30 patients. The ICRS objective evaluation showed at 7 year follow up that 76.7% of patients had good or excellent results [25].

Autologous chondrocyte implantation (ACI)

Autologous chondrocyte implantation is a procedure that was developed around the 1990s for treating damaged cartilage areas in the knee. The main premise behind ACI is to take healthy cells from the body, multiply them and then use the cells to fill the defect. The ACI procedure can be divided into two main phases: In the first phase an arthroscopy is performed. During the arthroscopy healthy cartilage cells are collected from a non-weight bearing area of the knee, the most common site for harvest is the supermedial edge of the femoral trochlea. Otherwise, the superolateral trochlear edge or the lateral aspect of the intercondylar notch can be used [26]. The cells are then sent to a laboratory to be cultured and multiplied. The chondrocytes will afterwards get separated from their surrounding cartilage and cultured for 4–6 weeks, reaching a number of 5–10 million cells.

During the second surgery, which usually takes place a month after the first, an open procedure is performed to implant the cultured cells. First-stage chondrocyte implantation involves direct injection of chondrocytes in suspension status into the defect, which then will attach within 12–24 h. To keep the cells in the defect area periosteum, or collagen membrane is sutured over the area and used as a cover [26]. The classic ACI technique provides good to excellent clinical results in 65–92% of cases [27].

A cell delivery vehicle carries out second-stage ACI, first cells are seeded on to biodegradable biomaterial, and then it is transplanted to the defect area. The seeded chondrocytes will either flow down to the subchondral bone, or the biomaterials will be degraded, and the chondrocytes will come off and attach to the subchondral bone. Kon et al. showed that after 21 days, a heterogeneous mix of cartilage-like matrix and mesenchymal tissue was observed throughout the defect [28]. Clinical use of the scaffold for autologous chondrocyte culture can overcome some of the difficulties of the classic ACI surgical technique such as reduction of operative time, eliminated the need for periosteal harvesting, and reduces the likelihood of postoperative complications [28].

Third-generation ACI, cells are seeded to the biomaterial, and cultivated for cartilage growth; transplantation is then carried out. The transplanted cartilage is expected to mature as normal cartilage. Tohyama H et al. reported significant improvement of the articular cartilage of the knee and showed that in arthroscopic findings that the appearance of normal cartilage was is 92% of patients [29].

ACI is ideally suitable for highly motivated, compliant patients between 15 and 55 years of age with symptomatic ICRS grade III and IV lesions in the femoral condyle or trochlear region. ACI is predominantly for lesions ranging from size 2 cm^2–16 cm^2 [30]. It should be used with patients who continue to have pain after mosaicplasty or microfracture procedures. After the ACI surgery the patient must follow an intensive rehabilitation program

Rehabilitation following ACI surgery

Cartilage maturation occurs through 3 phases after ACI [31]. The first phase (proliferative phase) occurs during the first 6 weeks, when implanted cells adhere to the subchondral bone. During this phase, the patient is allowed to toe-touch weight-bear with crutches. For activation of chondrocytes, many surgeons want continuous passive motion to be initiated as soon as possible on the day of implantation using a continuous passive motion machine (CPM) which provides neochondrogenesis, as shown by O'Drilscoll et al. [32]. The CPM should be used for 6–8 h a day for 4 weeks after surgery, aiming to have full range by the end of this period [31]. During the first 6 weeks, toe-touch weight bearing is allowed, from 6 to 10 weeks, the patient is allowed to weight-bear partially. Progressive flexion-extension exercises can be started aiming at a full range of movement by 6 weeks, if the ACI has been used to treat a cartilage defect in the patella or within the trochlea groove, motion must be limited for 2 months. Isometric quadriceps sets, straight leg raises, and hamstring strengthening should be introduced early, advancing to resistance exercises and then to functional activity. At 3 weeks closed chain exercises with light resistance can be initiated and open chain exercises can be added in the eighth week. Running is not advised until the eighth or ninth month, with high-impact level activities being initiated at 12 months. This progression is outlined in Table 3.

The second phase (transition phase) occurs during the next 4–6 months, in which matrix expansion progresses. From 6 to 10 weeks, partial weight bearing is allowed, and starting 10 weeks a gradual increase to full weight bearing. The third phase (remodeling phase) occurs during months 6–18, when cartilage tissue hardens to the firmness of the adjacent native cartilage. Although the patient is allowed to return to regular activities after 1 year, the graft continues to mature for up to 3 years [31]. These guidelines depend on the size, severity, and location of the cartilage injury.

Kreuz et al. [33] compared patients who participated indifferent levels of sports activity after ACI. Patient were allowed to return to preoperative activity level, from low-impact sports, such as running on grass after 4 months, to contact sports, such as basketball, after 12 months. Patients who participated in regular or competitive sports showed significantly better results in International Cartilage Repair Society and Cincinnati scores than patients with little or no involvement in sports. Improvement was shown over time, up to 36 months, therefore, physical training for at least 2 years after surgery was recommended.

In a study comparing OATS to microfracture, Gudas performed a randomized controlled trial with 57 athletes. Twenty-eight had OATS and 29 had microfractures with an average follow-up of 37 months. All lesions were 1 $cm^2$to 4 cm^2. Results at 3 years showed 96% of the patients in the OATS group showed good to excellent results compared to 57% of the microfracture group. When comparing return to sport, 93% of patients who underwent OATS were able to return to sport at 6 months while only 52% of patients with microfracture procedures were able to return at the same time. The authors performed biopsies of the repair cartilage at 1 year in 25 of the patients. The patients who underwent microfracture all had fibrocartilaginous repair while the patients in the OATS group retained their hyaline cartilage [34].

In comparing OATS vs. microfracture in knees for children, Gudas et al. followed 50 children with osteochondritis dissecans (OCD) in the femoral condyle. The lesions were grade 3 or 4 in the ICRS. Twenty-five patients were in the OAT group and 22 in the microfracture (MF) group. The mean follow-up was 4.2 years. After 1-year follow-up, both groups had significant clinical improvement ($P<0.05$) and the ICRS functional and objective assessment showed that 92% patients had excellent or good results after OAT and 86% after MF. But after 4.2 years 83% of OAT and only 63% of MF had maintained excellent or good results. ICRS

Table 3 Rehabilitation considerations following ACI

Autologous Chondrocyte Implantation (ACI)	
Assistive Devices	Crutches and hinged knee orthosis locked in full extension for all lesions.
Weight Bearing	Condylar lesions: TTWB for initial 6 weeks
	Patellar/Trochlear lesions: TTWB initiated 2 weeks then progressed to 50% by wk 3, 75% by wk 4–5, and FWB at wk 10
	*Wean off crutches by wk 8 for all lesions unless otherwise directed by surgeon
CPM	4–6 h/day starting 0–40° and advancing 5–10°/day
ROM	Passive knee flexion of 90° by 2 weeks, 120° by 4 weeks, and full PROM by 6 weeks.
Strengthening	Weeks 0–6: QS, SLRs-4way, ankle PREs, stationary bike when 100° of knee flexion achieved. At 3 weeks progressive closed chain exercises with light resistance, water walking at 4 weeks in waist high water, isometric leg press at 4 weeks, active knee extension 90–40° without resistance for condylar lesions; not permitted for patellar/trochlear lesions.
	Weeks 6–12: Mini-squats 0–45°, leg press, wall sits, TKEs, calf raises, treadmill walking, aquatic treadmill/pool walking program. At around 8 weeks open chain exercises can be initiated
	Femoral condyle lesions: open chain knee extensions and front/lateral step-ups.
	Patellar/Trochlear lesions: no knee extensions, leg press 0–60°, front/lateral step-ups at wk 8.
	Weeks 12–26: leg press 0–90°, squats 0–60°, front/lateral step-ups, hip stabilizer strengthening, walking program, bicycle, elliptical, stairmaster.
	Femoral condyle lesions: forward lunges and open chain knee extension 0–90°.
	Patellar/Trochlear lesions: backward lunges and open chain knee extension (Initiate 0–30°)
	*Light running can be initiated for all lesions at 24–26 weeks per physician clearance.
	Weeks 26–52+:
	• 6 months - golf, swimming, skating/blading.
	• 8–9 months - jogging, running, aerobics.
	• 12 months - tennis, basketball, football, baseball

For all surgeries:

*Establish full passive extension immediately post-op

*Assistive devices discontinued when the following criteria are met:

- Full knee extension
- Knee flexion = 100°
- No extensor lag
- Ambulate pain-free without gait abnormalities

evaluation system showed excellent or good repairs in 91% after OAT compared with 56% after MF [35•].

Harris et al. did a systematic review on athletes that compared microfracture vs., ACI, vs. OATs. Better clinical outcomes were observed after ACI and OATS versus microfracture, results after microfracture tended to deteriorate with time. Overall rate of return to preinjury level of sports was 66%. The timing of return to the preinjury level of sports was fastest after OATS and slowest after ACI. Defect size of less than 2 cm^2, duration of symptoms of less than 18 months prior to surgery, no prior surgical treatment, and younger patients all correlated with improved outcomes after cartilage repair, especially ACI. Results after microfracture were worse with larger defects. The rate of return to sports was generally lower after microfracture versus ACI or OATS. Also if a patient was able to return to sports, performance was diminished [36].

Conclusion

The focus of this manuscript has been on articular cartilage pathology as it relates to microfracture, OATS, and ACI. Important factors for the orthopedist to consider are the characteristics of the lesion as well as the age and activity level of the patient. Based on the literature discussed throughout this manuscript, microfracture is a good first-line option in treating smaller osteochondral defects (<2 cm^2), while OATs and ACI seems to be the surgical procedure of choice for more active patients with larger lesions (>2 cm^2) [37], or as a second line of treatment of these lesions (i.e. failed microfracture). The role of all the procedures is promising, but may require additional research before drawing definitive conclusions. Rehabilitation is premised on exposing the knee to a controlled amount force without overstressing healing tissues while gradually restoring full function. Through the cooperative efforts of the surgeon, therapist, and patient, restoration of a smooth gliding knee is possible in the face of articular cartilage pathology.

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References

Papers of particular interest, published recently, have been highlighted as:
• Of importance

1. Curl WW, Krome J, Gordon ES, Rushing J, Smith BP, Poehling GG. Cartilage injuries: a review of 31, 516 knee arthroscopies. Arthroscopy. 1997;13:456–60.
2. Aroen A, Loken S, Heir S, et al. Articular cartilage lesions in 993 consecutive knee arthroscopies. Am J Sports Med. 2004;32:211–5.
3. Hjelle K, Solheim E, Strand T, Muri R, Brittberg M. Articular cartilage defects in 1,000 knee arthroscopies. Arthroscopy. 2002;18:730–4.
4. Piasecki DP, Spindler KP, Warren TA, Andrish JT, Parker RD. Intraarticular injuries associated with anterior cruciate ligament tear: findings at ligament reconstruction in high school and recreational athletes: an analysis of sex-based differences. Am J Sports Med. 2003;31:601–5.
5. Shelbourne KD, Jari S, Gray T. Outcome of untreated traumatic articular cartilage defects of the knee: a natural history study. J Bone Joint Surg [Am]. 2003;85-A Suppl 2:8–16.
6. Insall J. The Pridie debridement operation for osteoarthritis of the knee. ClinOrthopRelat Res. 1974;101:61–7.
7. Steadman JR, Rodkey WG, Briggs KK, Rodrigo JJ. The microfracture procedure: rationale, technique, and clinical observations for treatment of articular cartilage defects. J Sports Traumatolrel Res. 1998;20(2):61–70.
8. Mithoefer K, Williams 3rd RJ, Warren RF, Wickiewicz TL, Marx RG. High-impact athletics after knee articular cartilage repair: a prospective evaluation of the microfracture technique. Am J Sports Med. 2006;34(9):1413–8.
9. Kreuz PC, Erggelet C, Steinwachs MR, Krause SJ, Lahm A, Niemeyer P, et al. Is microfracture of chondral defects in the knee associated with different results in patients aged 40 years or younger? Arthroscopy. 2006;22(11):1180–6.
10. Mithoefer K, Williams 3rd RJ, Warren RF, et al. Chondral resurfacing of articular cartilage defects in the knee with the microfracture technique. Surgical technique. J Bone Joint Surg Am. 2006;88 suppl 1:294–304.
11. Gill TJ, McCulloch PC, Glasson SS, Blanchet T, Morris EA. Chondral defect repair after the microfracture procedure: a nonhuman primate model. Am J Sports Med. 2005;33(5):680–5.
12. Honig K, Vidal A, McCarty E. Microfracture. Tech Knee Surg. 2009;8:7–13.
13. Rodrigo JJ, Steadman JR, Silliman JF, Fulstone HA. Improvement of full-thickness chondral defect healing in the human knee after debridement and microfracture using continuous passive motion. Am J Knee Surg. 1994;7(3):109–16.
14. Steadman JR, Briggs KK, Rodrigo JJ, Kocher MS, Gill TJ, Rodkey WG. Outcomes of microfracture for traumatic chondral defects of the knee: average 11-year follow-up. Arthroscopy. 2003;19(5):477–84.
15. Gobbi A, Nunag P, Malinowski K. Treatment of full thickness chondral lesions of the knee with microfracture in a group of athletes. Knee Surg Sports TraumatolArthrosc. 2005;13:213–21.
16. Yamashita F, Skakida K, Suzu F, et al. The transplantation of an autogeneic osteochondral fragment for osteochondritisdissecans of the knee. ClinOrthopRelat Res. 1985;201:43–50.
17. Feeley BT, Rodeo SA. Osteochondral allograft transplantation. Tech Knee Surg. 2009;8:22–8.
18. Matsusue Y, Kubo M, Nakagawa Y. Autogenous bone-cartilage transplantation. Tech Knee Surg. 2010;9:85–94.
19. Reddy S, Ma B, Feeley BT. Autologous osteochondral grafting of articular lesions in the knee. Tech Knee Surg. 2009;8:14–21.
20. Whiteside RA, Bryant JT, Jakob RP, Mainil-Varlet P, Wyss UP. Short term load bearing capacity of osteochondral autografts implanted by the mosaicplasty technique: an in vitro porcine model. J Biomech. 2003;36:1203–8.
21. Hangody L, Kish G, Karpati Z. Autogenous osteochondral graft technique for replacing knee cartilage defects in dogs. Orthop Int. 1997;5:175–81.
22. • Lahav A., Burks RT., Greis PE., Chapman AW., Ford GM., Fink BP.: Clinical outcomes following osteochondral autologous transplantation (OATS).J Knee Surg. 2006 Jul;19(3):169-73. *This study demonstrates that osteochondral autologous transplantation (OATS) is an option for articular resurfacing of the femoral condyles for focal areas of chondral defects with promising results.*
23. Hangody L, Vasarhelyi G, Hangody LR, et al. Autologous osteochondral grafting –technique and long term results. Injury. 2008;39 suppl 1:S32–9.
24. Jakob RP, Franz T, Gautier E, Mainil-Varlet P. Autologous osteochondral grafting in the knee: indications, results and reflections. ClinOrthopRelat Res. 2002;401:170–84.
25. Marcacci M, Kon E, Delcogliano M, et al. Arthroscopic autologous osteochondral grafting for cartilage defects of the knee: prospective study results at a minimum 7- year follow-up. Am J Sports Med. 2007;35:2014–21.
26. Min BH, Oh KS. Autologous Chondrocyte Implantation. Tech Knee Surg. 2010;9:66–79.
27. Jones DG, Peterson L. Autologous chondrocyte implantation. J Bone Joint Surg Am. 2006;88:2502–20.
28. Kon E, Gobbi A, Filardo G, et al. Arthroscopic second-generation autologous chondrocyte implantation compared with microfracture for chondral lesions of the knee: prospective nonrandomized study at 5 years. Am J of Sports Med. 2009;37:33–41.
29. Tohyama H, Yasuda K, Minami A, et al. Atelocollagen-associated autologous chondrocyte implantation for the repair of chondral defects of the knee: a prospective multicenter clinical trial in japan. J Orthop Sci. 2009;14:579–88.
30. Carey-Smith R, Ebert J, Davies H, et al. Arthroscopic matrix-induced autologous chondrocyte implantation: a simple surgical technique. Tech Knee Surg. 2010;9:170–5.
31. Jones DG, Peterson L. Autologous Chondrocyte Implantation. J Bone Joint Surg Am. 2006;88:2502–20.
32. O'Driscoll SW, Salter RB. The repair of major osteochondral defects in joint surfaces by neochondrogenesis with autogenousosteoperiosteal grafts stimulated by continuous passive motion. An experimental investigation in the rabbit. ClinOrthopRelat Res. 1986;208:131–40.
33. Kreuz PC, Steinwachs M, Erggelet C, et al. Importance of sports in cartilage regeneration after autologous chondrocyte implantation: a prospective study with a 3-year follow-up. Am J Sports Med. 2007;35:1261–8.
34. Gudas R, Kalesinskas RJ, Kimtys V, Stankevicius E, Toliusis V, Bernotavicius G, et al. A prospective randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint in young athletes. Arthroscopy. 2005;21(9):1066–75.

35. • Gudas R, Simonaityte R, Cekanauskas E, Tamosiunas R. A Prospective, Randomized Clinical Study of Osteochondral Autologous Transplantation Versus Microfracture for the Treatment of OsteochondritisDissecans in the Knee Joint in Children. *PediatrOrthop.* 2009:29:741–748. *This clinical, level 1 study in young active athletes under the age of 40 showed significant advantage of OATS over MF for the repair of articular cartilage defects in the knee. The authors found that only 52% of MF athletes could return to sports at the preinjury level compared to 93% of OATS.*
36. Harris J, Brophy R, Siston R, Flanigan D. Treatment of chondral defects in the athlete's knee. Arthroscopy. 2010;26:841–52.
37. Burns T, Giuliani J, Svoboda S, Owens B. Knee caritlagetibiofemoral injuries. Tech Orthop. 2010;25:208–16.
38. • Reinold MM, Wilk KE, Maacrina LC, et al. Current Concepts in the rehabilitation following articular cartilage repair procedures in the knee. *J Orthop Sports PhysTher.* 2006;36:774–794. *This paper provides an excellent adjunct to the current paper and an overview the principles of rehabilitation following articular cartilage repair procedures. It includes specific rehabilitation guidelines following surgery based upon the current understanding of the biological healing response postoperatively.*