Rehabilitation After Autologous Chondrocyte Implantation in Athletes

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Articular cartilage is a vital joint structure as evidenced by the progressive, painful, and debilitating loss of joint function that occurs when it becomes damaged. The importance of articular cartilage is evident in large, weight-bearing joints of the body, particularly the hip, knee, shoulder, and ankle, which are subjected to tremendous shear, tensile, and compressive forces with daily activities. Athletes may also sustain focal chondral injuries after an acute traumatic event, or insidiously, secondary to repetitive overuse due to the abnormal joint demands. Over the years a variety of cartilage restorative procedures have been developed to address focal, full-thickness cartilaginous defects in the knee joint, including microfracture, osteochondral autografts, osteochondral allografts, autologous chondrocyte implantation (ACI), and most recently, next-generation ACI involving scaffolds or cell-seeded scaffolds. Since its introduction, ACI has yielded some very promising results in athletes and nonathletes alike. Rehabilitation following ACI requires an in-depth understanding of joint mechanics, and knowledge of the biologic and biomechanical properties of healing articular cartilage. A patient-, lesion-, and sports-specific approach is required on the part of the trainer or physical therapist to gradually restore knee joint function and strength so that the athlete may be able to return to competitive play.

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ATHLETES TREATED WITH ACI

Cartilaginous defects are typically caused by repetitive shear forces, torsional loads, or high-impact stress.[1] The prevalence of these lesions in the general public is difficult to determine but estimates suggest that approximately 5% of the population have a focal, full-thickness cartilaginous defect.[1] Among patients undergoing knee arthroscopy, the prevalence of full-thickness defects is much higher. One series of 31,516 knee arthroscopies noted a 63% prevalence of chondral lesions, with 19.2% having grade IV chondromalacia.[2]

The prevalence of articular cartilage abnormalities in a general athletic population is not known but is thought to be much higher than the general population. There are sports-specific articular cartilage injury patterns depending on the type of physical demands on the knee. In a study by Walczak and colleagues,[3] 14 male National Basketball Association (NBA) players obtained bilateral knee magnetic resonance imaging (MRI) before the start of the season to evaluate for abnormalities in asymptomatic players with MRI. The investigators determined that 25 of 28 (89.3%) knees had abnormalities on routine preseason MRI for asymptomatic knees. Fifty percent of the players had an abnormal signal in the articular cartilage, which was consistent with the findings of 2 other studies that reported the prevalence of abnormal articular cartilage in 41% of collegiate basketball and 47.5% of NBA players.[4,5] The incidence of cartilaginous joint abnormalities in the general population was estimated at 3.7% in another study.[6] Eckstein and colleagues[7] conducted studies using MRI and 3-dimensional digital image analysis to determine the amount of cartilage deformation with certain activities. These investigators determined that cartilage deformation was significantly higher in the patellofemoral joint than the tibiofemoral joint.[7] Given the amount of jumping and direct knee contact in basketball players, it is not surprising that there is such a high prevalence of patellofemoral joint articular cartilage injuries. Mithofer and colleagues[8] reported that in high-level soccer players 48% of cartilage defects occurred on the medial femoral condyle, 23% occurred on the lateral femoral condyle, and only 29% occurred in the patellofemoral joint. Although the clinical examination is critical when evaluating an in-season injury, the investigators advocate that a preseason MRI for professional athletes is extremely helpful in providing information on interval change in the setting of a new injury and providing prognostic information related to decisions regarding return to play.[3]

There are certain patient- and lesion-specific factors associated with an improvement in knee functional outcomes as well as the ability to return to play.[8,9] For example, younger patient age has been associated with more favorable outcomes in several studies.[8–12] Cartilage injuries in competitive adolescent or young adult athletes may occur after an acute traumatic injury or injury to the cartilage secondary to osteochondritis dissecans (OCD).[9] In skeletally immature patients, these injuries generally result from a shearing force through the zone of provisional calcification of the open physis, which is structurally similar to the articular cartilage.[9] Acute treatment with either repair or replacement results in a higher potential for healing in younger patients.[13] However, Mithofer and colleagues[8] reported that there was no statistically significant difference between the clinical outcomes scores or return to play in a cohort of 20 soccer players treated with ACI in terms of the status of the physis or the mechanism of injury (an acute traumatic episode or OCD).[8,14] The investigators also determined that the mean age of patients that returned to sport was 22.3 years versus 27.6 years in patients who did not return to sport, and there was also a higher proportion of high-level athletes among patients who returned to sport.[8] There are several reasons for improved outcomes in high-level athletes, including acuity of injury, younger age, improved rehabilitation, and higher motivation.[8,15]

The duration of symptoms has been reported by several studies to affect the functional outcome.[8,16] ACI performed within 1 year after injury has a much higher likelihood of a return to preinjury level of sports compared with those that are treated after a prolonged period of symptoms. Although there are no definitive reasons for lower rate of return, chronic cartilage lesions may increase in size, affect the opposite articular surface, and contribute to an unfavorable repair environment. The delay in treatment also affects the ability to return to preinjury levels of sports due to deconditioning or relative inactivity.[8,17] Several studies have demonstrated that the number of prior procedures may also affect the overall functional outcome and return to preinjury athletics.[8,18,19]

Lesion characteristics also affect the overall knee function. Larger lesions have been reported to have less favorable results as well as knees with more than one cartilage lesion.[8,18,20,21] Medial femoral condyle articular cartilage injures also have been shown to have improved outcomes over other areas of the knee. Concomitant abnormalities including malalignment, meniscal deficiency, and ligamentous instability increase the complexity of the operative intervention but also improve the clinical outcomes in patients undergoing cartilage repair. For example, in one study there was no significant difference between soccer players who underwent isolated ACI and those who underwent ACI with osteotomy, meniscus repair, or anterior cruciate ligament reconstruction in terms of return to play.[8] In fact, failure to recognize and treat combined pathology may result in repeat surgical intervention and prolonged rehabilitation. The results of ACI in general are well reported in the literature, and support good to excellent outcomes in both the patellofemoral and tibiofemoral joint.[22–24]

BIOLOGY OF ACI HEALING

The rationale behind the development of ACI for the treatment of full-thickness chondral injuries is based on the unique biology of articular cartilage. In well-vascularized tissue, inflammatory mediators are recruited to aid in the healing process. However, articular cartilage has poor vascular supply, hindering its ability to repair cartilage damage.[1,25,26] Despite early research in the 1980s by Grande and colleagues[27] that highlighted the ability of chondrocytes to replicate when isolated enzymatically from their matrix, in vivo they have a very limited capacity to migrate to sites of injury.[28] Left alone, full-thickness articular cartilage defects will, at best, not heal, and more likely continue to enlarge by circumferential expansion, exposing increasing amounts of subchondral bone, potentially predisposing the knee to accelerated arthrosis. Because the average depth of articular cartilage on the femur, patella, and knee are only 2.0, 3.33, and 2.92 mm, respectively, even partial-thickness lesions may progress to exposed subchondral bone with even minor degrees of defect progression.[29]

Of critical importance in the rehabilitation process following ACI is graft incorporation, maturation, and production of extracellular matrix. Understanding the timeline for tissue maturation helps to guide the principles of postoperative rehabilitation such that tissue development is promoted while simultaneously preventing mechanical overload from occurring. A significant advantage of ACI over other procedures that aim to fill contained articular cartilage defects is the formation of predominantly hyaline or hyalinelike cartilage.[30] Although the ultimate goal of cartilage transplantation procedures is to restore the structure of native cartilage on both a microscopic and macroscopic level, the process is not instantaneous and requires a complex, temporal cascade of cellular division and incorporation into host tissue. Whereas the specific details of this intricate cascade are generally unknown, various studies have looked at the histology of graft tissue at various periods after implantation.

Canine studies have been instrumental in highlighting the various stages of chondrocyte healing.[31] The first 6 weeks constitute the proliferative phase of healing whereby a primitive cellular response leads to tissue fill of the defect. Grande and colleagues[27] demonstrated that within 6 weeks of implantation, autologous chondrocytes underwent significant division and became incorporated into reconstituted cartilage matrix. Their work solidified the idea that the transplanted cells survive and divide after transplantation, and do not merely act to induce articular growth from within the host's intact cartilage matrix. A transition phase, lasting from 3 to 6 months, follows the proliferative response. During this crucial period proteoglycan production occurs, although it is still poorly integrated and takes on a more fluid consistency. At the 6-month time point the graft is usually firm and has incorporated into adjacent articular cartilage and subchondral bone, which typically correlates with a reduction in a patient's symptoms. Remodeling and maturation take place on larger time scales, between 2 and 3 years following ACI. The seminal events during this period include the formation of cross-links between matrix proteins and aggregate formation leading to improved stability and integration into subchondral bone. Throughout all these stages of graft healing a fine balance must be maintained to promote matrix synthesis and graft incorporation without exposing the chondrocytes to excessive loads.[31]

In a translational project by Brittberg and colleagues,[32] the group demonstrated histologic changes over time in the rabbit patellae. At 8 and 12 weeks following ACI, the implanted chondrocytes demonstrated rich cluster formation indicating mitotic activity. Exactly 1 year following ACI, the histologic characteristics of the repaired cartilage appeared more columnar in nature and showed signs of integration with the adjacent, healthy cartilage.

REHABILITATION PROTOCOL

The rehabilitation protocol is critical for successful recovery from ACI surgery and return to high-demand athletic activity. It is generally accepted that the 3 phases of the maturation process for ACI rehabilitation are proliferative, matrix production, and maturation phases.[33,34] The proliferative phase occurs soon after implantation of the autologous chondrocytes, followed by matrix production in which the tissue becomes incorporated into the surrounding host cartilage.[35] In the recovery phase, the ACI continues to mature and the biomechanical properties begin to resemble the surrounding articular cartilage. These goals are achieved by a combination of progressive weight bearing, restoration of range of motion, improving muscle control and strengthening, and sport-specific activities.

Phase 1: Femoral Condyles

Many studies have shown the importance of joint motion after cartilage implantation. Continuous passive motion (CPM) postoperatively, as well as weight-bearing activities, are associated with proteoglycan and collagen reorganization.[36,37] Weight-bearing activity is typically withheld until after the first 2 weeks of implantation to preserve physical properties of the graft. In subsequent studies looking at long-term outcomes for ACI, histologic analysis demonstrated that biopsies from weight-bearing surfaces appeared to resemble organized hyaline cartilage with type II collagen. Biopsies in nonweight-bearing areas resembled fibrocartilage.[25] Peterson and colleagues[25] reported that the biopsied samples demonstrating a hyalinelike cartilaginous content do, in fact, have a superficial fibrous layer indicating periosteal remnant. This finding did not affect the clinical success of the graft.

Traditional thinking asserts that a graduated program of weight bearing and controlled exercise will provide a healthy intra-articular environment for the graft.[38,39] Such protocols recommend an initial 2 weeks of nonweight bearing (NWB) followed by partial weight bearing (PWB) up until 4 weeks after surgery (**Tables 1** and **2**). From 4 to 6 weeks, the patient may progress to the use of one crutch, with gradual increases in load over the following 6 weeks so that full weight bearing (FWB) occurs by week 12.[40] Investigators working with second- and third-generation ACI techniques employing collagen scaffolds (CACI) and matrix-induced ACI (MACI), respectively, recently have advocated more aggressive rehabilitation regimens. Robertson and colleagues[38] still advocate obtaining FWB by the twelfth postoperative week. However, rather than having an initial 6 weeks of toe-touch ambulation only, they believe patients should gradually progress from 20% of their body weight (BW) at 2 weeks after the operation through to FWB at 12 weeks. In a randomized controlled trial of patients undergoing MACI, Ebert and colleagues[41] found that compared with a standard rehabilitation regimen, patients in the accelerated rehabilitation group (FWB achieved by eighth postoperative week) had reduced knee pain, improved function, and greater 6-minute walk distances and daily activity levels. However, because MACI is often performed in a less invasive fashion and is performed without periosteal sutures compared with first-generation ACI, such accelerated protocols may not be applicable to conventional ACI.[42] The authors' current approach, especially for contained lesions, involves initial heel-touch or toe-touch weight bearing, as this has not been shown to be detrimental to graft integration and facilitates transition activities (ie, arising from a bed or chair to a standing position), which are very difficult for patients to perform when completely NWB. In addition, the authors use a brace that has off-loading capability (TROM Adjuster; Don Joy Orthopedics, Carlsbad, CA, USA), which incorporates the same 3-point bending principles as a brace typically prescribed for osteoarthritis. As weight bearing is advanced, the maximal amount of off-loading that the patient can tolerate to facilitate relative unicompartmental unloading is "dialed in" while the patient is simultaneously reactivating frontal and posterior chain musculature.

A knowledge of joint kinematics, taking into account the areas of contact, loads, and pressures generated during normal joint movements, is essential for designing rational rehabilitation protocols that minimize damage to the graft and promote healing (see **Tables 1** and **2**). The tibiofemoral joint (TFJ), a modified hinge joint, possesses 6 degrees of freedom that result in a combination of rolling and gliding as the knee moves through flexion to extension.[43,44] Safe rehabilitation protocols must minimize shear and compressive forces on the articular cartilage. For the initial 2 weeks, the patient is placed in a locked, hinged knee brace in extension for ambulation, but this may be removed for CPM and exercise. Over the next 2 weeks, the brace can be gradually opened 20° at a time as quadriceps control is regained, and the brace may be discontinued when the quadriceps is able to control a straight leg raise without an extension lag. CPM is used for the first 4 weeks for 6 to 8 hours per day at 1 cycle per minute, beginning at 0° to 30° increasing roughly 5° to 10° daily, with the goal of 90° by week 4 and 120° to 130° by week 6. Therapeutic exercise begins with attempting to restore quadriceps control with quad sets, straight leg raises, and hamstring isometrics for the first 2 weeks. Closed chain exercises are initiated between 2 and 6 weeks after surgery, with progressive strengthening over the course of the first 3 months. Again, knowledge of defect location is necessary, because during many activities only certain aspects of the TFJ are in contact.[43,45] If the ACI site is located in the anterior aspect of the joint, full extension with closed chain activities is to be

Table 1
Autologous chondrocyte implantation (femoral condyle only) rehabilitation protocol

	Weight Bearing	Brace	Rom	Therapeutic Exercise
PHASE 1 (0–12 weeks)	**0–2 weeks**: Nonweight bearing **2–4 weeks**: Partial weight bearing (30–40 lbs) **4–6 weeks**: Progress to use of one crutch **6–12 weeks**: Progress to full weight bearing	**0–2 weeks**: Locked in full extension (removed for CPM and exercise) **2–4 weeks**: Gradually open brace 20° at a time as quad control is gained; discontinue use of brace when quads can control straight leg raises without an extension lag	**0–4 weeks:** CPM: use in 2-h increments for 6–8 h per day at 1 cycle/min—begin at 0°–30° increasing 5°–10° daily per patient comfort; patient should gain at least 90° by week 4 and 120°–130° by week 6	**0–2 weeks**: Quad sets, straight leg raises, hamstring isometrics; complete exercises in brace if quad control is inadequate **2–6 weeks**: Begin progressive closed chain exercises[a] **6–10 weeks**: Progress bilateral closed chain strengthening, begin opened chain knee strengthening **10–12 weeks**: Progress closed chain exercises using resistance less than patient's body weight, progress to unilateral closed chain exercises, begin balance activities
PHASE 2 (12 weeks to 6 months)	Full with a normalized gait pattern	None	Full active range of motion	Advance bilateral and unilateral closed chain exercises with emphasis on concentric/eccentric control, continue with biking, stairmaster and treadmill, progress balance activities

PHASE 3 (6–9 months)	Full with a normalized gait pattern	None	Full and pain free	Advance strength training, initiate light plyometrics and jogging—start with 2-min walk/2-min jog, emphasize sport-specific training
PHASE 4 (9–18 months)	Full with a normalized gait pattern	None	Full and pain free	Continue strength training—emphasize single leg loading, begin a progressive running and agility program; high-impact activities (basketball, tennis, etc) may begin at 16 months if pain free

[a] Respect chondrocyte graft site with closed chain activities: if anterior, avoid loading in full extension; if posterior, avoid loading in flexion >45°.
[b] If pain or swelling occurs with any activities, they must be modified to decrease symptoms.

Table 2
Autologous chondrocyte implantation (trochlea/patella)[a] rehabilitation protocol

	Weight Bearing	Brace	Rom	Therapeutic Exercise
PHASE 1 (0–12 weeks)	**0–2 weeks**: Nonweight bearing **2–4 weeks**: Partial weight bearing (30–40 lbs) **4–8 weeks**: Continue with partial weight-bearing status, progress to use of one crutch **8–12 weeks**: Progress to full weight bearing and discard crutches	**0–2 weeks**: Locked in full extension (removed for CPM and exercise) **2–4 weeks**: Locked at 0° with weight bearing **4–6 weeks**: Begin to open 20°–30° with ambulation; discontinue use after 6 weeks	**0–4 weeks**: CPM: use in 2-h increments for 6–8 h per day at 1 cycle/min—begin at 0°–30°; after week 3, increase flexion by 5°–10° daily **6–8 weeks**: Gain 0°–90° **8 weeks**: Gain 0°–120°	**1–4 weeks**: Quad sets, straight leg raises, hamstring isometrics—complete exercises in brace if quad control is inadequate **4–10 weeks**: Begin *isometric* closed chain exercises; at 6–10 weeks, may begin weight shifting activities with involved leg extended if full weight bearing; at 8 weeks begin balance activities and stationary bike with light resistance **10–12 weeks**: Hamstring strengthening, theraband 0°–30° resistance, light open chain knee isometrics
PHASE 2 (12 weeks to 6 months)	Full with a normalized gait pattern	None	Full range of motion	Begin treadmill walking at a slow to moderate pace, progress balance/ proprioceptive activities, initiate sport cord lateral drills

PHASE 3 (6–9 months)	Full with a normalized gait pattern	None	Full and pain free	Advance closed chain strengthening, initiate unilateral closed chain exercises, progress to fast walking and backward walking on treadmill (initiate incline at 8–10 months), initiate light plyometric activity
PHASE 4 (9–18 months)	Full with a normalized gait pattern	None	Full and pain free	Continue strength training—emphasize single leg loading, begin a progressive running and agility program; high-impact activities may begin at 16 months

Note: Postoperative stiffness in flexion following trochlear/patellar implantation is not uncommon, and patients are encouraged to achieve 90° of flexion at least 3 times/day out of the brace after their first postoperative visit (days 7–10).

[a] Most trochlear/patellar defect repairs are performed in combination with a distal realignment procedure.

[b] May consider patellofemoral taping or stabilizing brace if improper patella tracking stresses implantation.

[c] If pain or swelling occurs with any activities, they must be modified to decrease symptoms.

avoided. If the ACI site is posterior, loading in flexion greater than 45° with closed chain activities should be avoided.

Phase 1: Patellofemoral

The patellofemoral joint (PFJ) is designed to increase the mechanical advantage of the quadriceps mechanism while minimizing focal cartilage stresses by distributing force equally to the underlying bone. The patella has the thickest articular cartilage in the human body as well as a broad articulating surface.[46–48] At full, passive extension the patella rests on the supratrochlear fat pad, avoiding any contact with the femoral articular surface. Up to a certain point, increasing knee flexion results in concomitant increases in the patellofemoral joint reaction force (PFJRF) and contact areas. Initial contact between the patella and femur occurs at 10 degrees of flexion as the inferior pole of the patella engages the trochlea. At 60 degrees of flexion, the middle surface of patella makes contact with the middle third of the trochlea. Over these 50 degrees, mean contact area increases from 126 to 560 mm^3.[35,49] Optimizing the PFJ contact area as opposed to decreasing the force promotes better nutrient exchange of the cartilage and decreases the pressure on the PFJ.[44,48,50,51]

Patellofemoral ACI is typically performed with tibial tubercle anteromedialization (AMZ), and the first phase of rehabilitation is slower than ACI of the femoral condyles.[22] Weight-bearing activity is typically limited to heel- or toe-touch weight bearing until after the 3 to 4 weeks of implantation, when an AMZ is performed to prevent a postoperative tibial shaft insufficiency fracture. When no AMZ is performed, the authors liberally advance to weight bearing as tolerated with crutches while locked in extension, as patellofemoral forces are not altered significantly with WB when in extension. A locked, hinged knee brace is used for the first 4 weeks and is removed for CPM or exercise. At 4 weeks, the hinged knee brace may be opened 20° to 30° with ambulation and may be discontinued after 6 weeks. CPM is initiated immediately after surgery for 6 to 8 hours per day beginning from 0° to 30° at 1 cycle per minute. After 3 weeks, the flexion may be increased to 5° to 10° daily with the goal of 90° by 6 to 8 weeks and 0° to 120° by 8 weeks after surgery. Because of their initial experience following patellofemoral ACI whereby there was a small incidence of difficulties in regaining full flexion, the authors encourage patients to achieve up to 90 degrees of flexion by simply dangling the foot while sitting in a chair for up to 3 times per day beginning at postoperative week 2.

Therapeutic exercise begins with attempting to restore quadriceps control with quad sets, straight leg raises, and hamstring isometrics for the first 4 weeks. Isometric closed chain exercises are initiated between 6 and 10 weeks after surgery, and patients may begin weight-shifting activities in extension. If FWB by 8 weeks, the patient may begin balance activities with light resistance on a stationary bicycle. The patient may continue progressive strengthening over the course of the first 3 months with the use of a theraband and light open chain knee isometrics.

Phase 2

By 3 months after surgery, the patient has recovered full active range of motion with a normalized gait pattern. Patients who have undergone ACI of the femoral condyles may continue to advance with closed chain activities with an emphasis on concentric/eccentric control. A stationary bicycle can be introduced early in the rehabilitation process, but it is important to use minimal resistance in the beginning to allow complete pedal revolution. The saddle height has a direct influence on knee flexion angles and needs to be appropriate for the specific ACI graft location.[52] For example, the lower the saddle height, the higher the patellofemoral joint reactive force; and the higher the saddle height, the lower the range of knee flexion.[39,53] Saddle height can be raised initially to allow a complete pedal revolution and restrict excessive knee flexion, but the seat should be lowered to the appropriate height as range of motion is restored. Other low-impact exercise modalities with a stair stepper, elliptical trainer, or treadmill can also be considered, but there is a lack of clinical and biomechanical data available.[39]

Patients who have undergone ACI of the patellofemoral joint may begin treadmill walking at a slow pace and may progress to a moderate pace. Neuromuscular re-education and proprioceptive activities are critical components for patellofemoral ACI rehabilitation. Patellofemoral pain syndrome has been reported to be associated with proprioceptive deficits.[54] The relationship between articular cartilage lesions and proprioception is not known; however, open procedures are thought to result in increased proprioceptive loss due to increased disruption of joint mechanoreceptors.[55,56] ACI rehabilitation should focus on restoring proprioception in a dynamic, functional manner with an emphasis on neuromuscular control to retrain coordination patterns.[39] In the early stages, patients are encouraged to vary movement speeds to target the feedback systems and progress to faster movements that focus on retraining the feed-forward system.[39] There are several exercises that can be performed, including eyes open to shut, 2-legged to 1-legged stance, unstable base, resistance or center of gravity shift, and sports-specific drills.[39]

Phase 3

At 6 to 9 months after surgery, the patient should continue the progressive strength training and transition to more functional activities. Patients should continue closed chain strengthening with a treadmill, beginning with a slow walking pace and eventually to a light jog over the course of the next 3 months. Patellofemoral patients should also incorporate backward walking on a treadmill at the 8- to 10-month time point. During this phase, athletes should also begin a core strengthening program and initiate plyometric activity.

Core stability is an important component of any lower extremity rehabilitation program and also has a role in postoperative ACI rehabilitation. A recent prospective study by Leetun and colleagues[57] measured the femoral abduction and external rotation isometric force as well as abdominal, back extension, and quadratus lumborum endurance in preseason intercollegiate athletes. Those athletes with weaker preseason femoral abduction and external strength were more likely to sustain an in-season injury.[57] Additional studies also support the participation of a neuromuscular training program for lower extremity injury prevention.[34,52]

Core strengthening should focus on isometric cocontractions of the lumbar multifidus and transversus abdominis during functional activities.[58] Patients should maintain a neutral spinal position and gently draw in the abdominal wall by contracting the lumbar multifidus.[59] The patient should begin to perform drawing-in exercises in positions of greater support and progress to functional positions while dissociating extremity movements. Specific core muscle strengthening exercises can be done with curl-ups or side planks. Equipment involving exercise balls, foam rollers, platforms, and balance boards can be implemented to increase external torque for further core strengthening. Strengthening of the hip abductors and external rotators are critical to maintain proper lower extremity alignment and prevention of potential knee injuries. The rationale behind a plyometric program is to train the muscles, connective tissue, and nervous system to carry out stretch-shortening cycle focusing of proper technique and mechanics.[60] A recent systematic review concluded that plyometrics, dynamic balance and strength, stretching, body awareness, decision-making, and targeted core and trunk control seem to reduce modifiable knee injury risk factors by decreasing landing forces, decreasing varus/valgus moments, and increasing effective muscle activation.[61] A plyometric exercise program should be implemented beginning with slow, controlled movements such as stepping up on a platform to faster, more explosive action such as jumping and landing.[59]

Phase 4: Sports-Specific Activities

From 9 to 18 months after surgery, the goal of the rehabilitation is to implement sports-specific activity and eventually return to competition. The timing of anticipated return to play will vary depending on patient-, lesion-, comorbid-, and sports-specific factors, but the athlete may not return before 9 months after ACI. The athlete should continue lower extremity strength training, core strengthening, and plyometric exercises. The athlete may begin a running program that may progress in duration and intensity over the course of the rehabilitation. The athlete should also focus on agility exercises that are specific to the sport of interest. When the patient is able to perform sports-specific activities without pain, he or she may be introduced into limited game situations. General guidelines are that low-impact sports such as swimming, skating, rollerblading, and cycling are permitted at about 9 months, higher-impact sports such as jogging and running at 9 to 12 months, and high-impact sports such as baseball, football, basketball, and tennis between 12 and 18 months.[62]

RETURN TO PLAY AFTER ACI

The duration of rehabilitation after ACI can vary depending on the individual patient, location of the ACI, concomitant procedures, and the type of sport. The appropriate recommendation for return to play can be difficult to ascertain from the literature because there are multiple factors that may lead an athlete to return to competition. In the series by Mithofer and colleagues[8] it was reported that whereas 72% reported good to excellent knee function, only 33% were able to return to soccer; however, 10 of 12 (83%) high-skill soccer players compared with only 5 of 31 (16%) recreational soccer players were able to return to the same level of competition. The mean time to return to soccer for high-skill players was 14.2 months. The disproportionate percentage of high-level athletes returning to the same level of competition has also been observed in patients undergoing microfracture surgery, with greater than 75% returning to play.[11,63] Some studies have reported that patients who underwent ACI or second-generation ACI have been active in competition for a longer period of time compared with athletes who underwent microfracture, suggesting that autologous chondrocyte implantation may provide a more durable treatment option.[8,11,63,64] There are several factors associated with high-level athletes returning to sports, including a younger age, shorter duration of symptoms, and improved postoperative rehabilitation.[8,11] In addition, there are psychosocial factors that may contribute to whether the patient ultimately returns to the same level of competition, as professional athletes have a socioeconomic incentive to return to play.

SUMMARY

The treatment of cartilage defects in the knee with ACI has been demonstrated to be a good treatment option for an athletic patient population. Although there are only a few studies that have looked at such a population, there are several factors that have been associated with a higher likelihood of return to play: younger age, less than 1 year of symptom duration, isolated lesion, and higher level of competition. Rehabilitation after ACI surgery is based on the biologic incorporation of the graft, graft location, and other concomitant procedures that are performed in the athlete. At 3 months, the athlete should have full range of motion with closed chain muscle strengthening. Between 6 and 9 months, the athlete should have full, pain-free range of motion, and a continuation of strength and conditioning with implementation of a core strengthening and a plyometrics program. The anticipated return to sports may vary depending on comorbidities and the patient-, lesion-, and sports-specific factors, but the athlete may not return earlier than 9 months and may take 12 to 18 months before a return to the same level of competition is possible. Careful, supervised rehabilitation with appropriate expectations should allow the athlete a safe and effective return to play that may provide a longer athletic career and a knee that is durable beyond the playing field.

REFERENCES

1. Jones D, Peterson L. Autologous chondrocyte implantation. J Bone Joint Surg Am 2006;88:2502–20.
2. Curl WW, Krome J, Gordon ES, et al. Cartilage injuries: a review of 31,516 knee arthroscopies. Arthroscopy 1997;13(4):456–60.
3. Walczak BE, McCulloch PC, Kang RW, et al. Abnormal findings on knee magnetic resonance imaging in asymptomatic NBA players. J Knee Surg 2008;21:27–33.
4. Major NM, Helms CA. MR imaging of the knee: findings in asymptomatic collegiate basketball players. AJR Am J Roentgenol 2002;179:641–4.
5. Kaplan LD, Schurhoff MR, Selesnick H, et al. Magnetic resonance imaging of the knee in asymptomatic professional basketball players. Arthroscopy 2005;21:557–61.
6. LaPrade RF, Burnett QM 2nd, Veenstra MA, et al. The prevalence of abnormal magnetic resonance imaging findings in asymptomatic knees. With correlation of magnetic resonance imaging to arthroscopic findings in symptomatic knees. Am J Sports Med 1994;22:739–45.
7. Eckstein F, Lemberger B, Gratzke C, et al. In vivo cartilage deformation after different types of activity and its dependence on physical training status. Ann Rheum Dis 2005;64:291–5.
8. Mithofer K, Peterson L, Mandelbaum BR, et al. Articular cartilage repair in soccer players with autologous chondrocyte transplantation: functional outcome and return to competition. Am J Sports Med 2005;33:1639–46.
9. Micheli L, Curtis C, Shervin N. Articular cartilage repair in the adolescent athlete: is autologous chondrocyte implantation the answer? Clin J Sport Med 2006;16:465–70.
10. Kocher MS, Micheli LJ, Yaniv M, et al. Functional and radiographic outcome of juvenile osteochondritis dissecans of the knee treated with transarticular arthroscopic drilling. Am J Sports Med 2001;29:562–6.
11. Blevins FT, Steadman JR, Rodrigo JJ, et al. Treatment of articular cartilage defects in athletes: an analysis of functional outcome and lesion appearance. Orthopedics 1998;21:761–7 [discussion: 767–8].
12. Kish G, Modis L, Hangody L. Osteochondral mosaicplasty for the treatment of focal chondral and osteochondral lesions of the knee and talus in the athlete. Rationale, indications, techniques, and results. Clin Sports Med 1999;18:45–66, vi.
13. Takahara M, Ogino T, Sasaki I, et al. Long term outcome of osteochondritis dissecans of the humeral capitellum. Clin Orthop Relat Res 1999;(363):108–15.
14. Mithofer K, Minas T, Peterson L, et al. Functional outcome of knee articular cartilage repair in adolescent athletes. Am J Sports Med 2005;33:1147–53.

15. Bjordal JM, Arnly F, Hannestad B, et al. Epidemiology of anterior cruciate ligament injuries in soccer. Am J Sports Med 1997;25:341–5.
16. Peterson L, Minas T, Brittberg M, et al. Two- to 9-year outcome after autologous chondrocyte transplantation of the knee. Clin Orthop Relat Res 2000;(374):212–34.
17. Jones G, Bennell K, Cicuttini FM. Effect of physical activity on cartilage development in healthy kids. Br J Sports Med 2003;37:382–3.
18. Hefti F, Beguiristain J, Krauspe R, et al. Osteochondritis dissecans: a multicenter study of the European Pediatric Orthopedic Society. J Pediatr Orthop B 1999;8: 231–45.
19. Peterson L, Minas T, Brittberg M, et al. Treatment of osteochondritis dissecans of the knee with autologous chondrocyte transplantation: results at two to ten years. J Bone Joint Surg Am 2003;85(Suppl 2):17–24.
20. Minas T. The role of cartilage repair techniques, including chondrocyte transplantation, in focal chondral knee damage. Instr Course Lect 1999;48: 629–43.
21. Mandelbaum B, Browne J, Fu F, et al. Articular cartilage lesions of the knee. Current concepts. Am J Sports Med 1998;26:853–61.
22. Pascual-Garrido C, Slabaugh MA, L'Heureux DR, et al. Recommendations and treatment outcomes for patellofemoral articular cartilage defects with autologous chondrocyte implantation. Prospective evaluation at average 4-year follow-up. Am J Sports Med 2009;37(Suppl 1):33S–41S.
23. McNickle AG, L'Heureux DR, Yanke AB, et al. Outcomes of autologous chondrocyte implantation in a diverse patient population. Am J Sports Med 2009;37(7): 1344–50.
24. Zaslav K, Cole BJ, Brewster R, et al. A prospective study of autologous chondrocyte implantation in patients with failed prior treatment for articular cartilage defects of the knee. Am J Sports Med 2008;36:1–14.
25. Peterson L, Brittberg M, Kiviranta I, et al. Autologous chondrocyte transplantation. Biomechanics and long-term durability. Am J Sports Med 2002;30(1):2–12.
26. Manning WK, Bonner WM Jr. Isolation and culture of chondrocytes from human adult articular cartilage. Arthritis Rheum 1967;10(3):235–9.
27. Grande DA, Pitman MI, Peterson L, et al. The repair of experimentally produced defects in rabbit articular cartilage by autologous chondrocyte transplantation. J Orthop Res 1989;7(2):208–18.
28. Smith AV. Survival of frozen chondrocytes isolated from cartilage of adult mammals. Nature 1965;205:782–4.
29. Ateshian GA, Soslowsky LJ, Mow VC. Quantitation of articular surface topography and cartilage thickness in knee joints using stereophotogrammetry. J Biomech 1991;24(8):761–76.
30. Grande DA, Singh IJ, Pugh J. Healing of experimentally produced lesions in articular cartilage following chondrocyte transplantation. Anat Rec 1987;218(2): 142–8.
31. Breinan HA, Minas T, Hsu HP, et al. Effect of cultured autologous chondrocytes on repair of chondral defects in a canine model. J Bone Joint Surg Am 1997;79(10): 1439–51.
32. Brittberg M, Nilsson A, Lindahl A, et al. Rabbit articular cartilage defects treated with autologous cultured chondrocytes. Clin Orthop Relat Res 1996;(326): 270–83.
33. Minas T, Chiu R. Autologous chondrocyte implantation. Am J Knee Surg 2000;13: 41–50.

34. Gillogly SD, Voight M, Blackburn T. Treatment of articular cartilage defects of the knee with autologous chondrocyte implantation. J Orthop Sports Phys Ther 1998; 28:241–51.
35. Alford AJ, Cole BJ. Cartilage restoration, part 2, techniques, outcomes, and future directions. Am J Sports Med 2005;33(3):443–60.
36. O'Driscoll SW, Keeley FW, Salter RB. The chondrogenic potential of free autogenous periosteal grafts for biological resurfacing of major full-thickness defects in joint surfaces under the influence of continuous passive motion. An experimental investigation in the rabbit. J Bone Joint Surg Am 1986;68(7):1017–35.
37. Reinold MM, Wilk KE, Macrina LC, et al. Current concepts in the rehabilitation following articular cartilage repair procedures in the knee. J Orthop Sports Phys Ther 2006;36(10):774–94.
38. Robertson WB, Gilbey H, Ackland T. Standard practice exercise rehabilitation protocols for matrix induced autologous chondrocyte implantation femoral condyles. Perth (Western Australia): Hollywood Functional Rehabilitation Clinic; 2004.
39. Hambly K, Bobic V, Wondrasch B, et al. Autologous chondrocyte implantation postoperative care and rehabilitation: science and practice. Am J Sports Med 2006;34(6):1020–38.
40. Minas T, Peterson L. Advanced techniques in autologous chondrocyte transplantation. Clin Sports Med 1999;18:13–44, v–vi.
41. Ebert JR, Robertson WB, Lloyd DG, et al. Traditional vs accelerated approaches to post-operative rehabilitation following matrix-induced autologous chondrocyte implantation (MACI): comparison of clinical, biomechanical and radiographic outcomes. Osteoarthritis Cartilage 2008;16(10):1131–40.
42. Wood D, Zheng M, Robertson B. An Australian experience of ACI and MACI. In: Bentley G, editor. Current developments in autologous chondrocyte implantation, round table series, vol. 77. London: Royal Society of Medicine Press Ltd; 2003. p. 7–16.
43. Patel VV, Hall K, Ries M, et al. A three-dimensional MRI analysis of knee kinematics. J Orthop Res 2004;22(2):283–92.
44. McGinty G, Irrgang JJ, Pezzullo D. Biomechanical considerations for rehabilitation of the knee. Clin Biomech (Bristol, Avon) 2000;15(3):160–6.
45. Martelli S, Pinskerova V. The shapes of the tibial and femoral articular surfaces in relation to tibiofemoral movement. J Bone Joint Surg Br 2002;84(4):607–13.
46. Grelsamer RP, Klein JR. The biomechanics of the patellofemoral joint. J Orthop Sports Phys Ther 1998;28(5):286–98.
47. Lee TQ, Morris G, Csintalan RP. The influence of tibial and femoral rotation on patellofemoral contact area and pressure. J Orthop Sports Phys Ther 2003;33(11): 686–93.
48. McConnell J. The physical therapist's approach to patellofemoral disorders. Clin Sports Med 2002;21(3):363–87.
49. Powers CM, Ward SR, Fredericson M, et al. Patellofemoral kinematics during weight-bearing and non-weight-bearing knee extension in persons with lateral subluxation of the patella: a preliminary study. J Orthop Sports Phys Ther 2003; 33(11):677–85.
50. Cohen NP, Foster RJ, Mow VC. Composition and dynamics of articular cartilage: structure, function, and maintaining healthy state. J Orthop Sports Phys Ther 1998;28(4):203–15.
51. Irrgang JJ, Pezzullo D. Rehabilitation following surgical procedures to address articular cartilage lesions in the knee. J Orthop Sports Phys Ther 1998;28(4): 232–40.

52. Fuchs S, Thorwesten L, Niewerth S. Proprioceptive function in knees with and without total knee arthroplasty. Am J Phys Med Rehabil 1999;78:39–45.
53. Ericson MO, Nisell R. Patellofemoral joint forces during ergometric cycling. Phys Ther 1987;67:1365–9.
54. Baker V, Bennell K, Stillman B, et al. Abnormal knee joint position sense in individuals with patellofemoral pain syndrome. J Orthop Res 2002;20:208–14.
55. Fremerey RW, Lobenhoffer P, Zeichen J, et al. Proprioception after rehabilitation and reconstruction in knees with deficiency of the anterior cruciate ligament: a prospective, longitudinal study. J Bone Joint Surg Br 2000;82:801–6.
56. Hess T, Gleitz M, Hopf T, et al. Changes in muscular activity after knee arthrotomy and arthroscopy. Int Orthop 1995;19:94–7.
57. Leetun DT, Ireland ML, Willson JD, et al. Core stability measures as risk factors for lower extremity injury in athletes. Med Sci Sports Exerc 2004;36(6):926–34.
58. Richardson CA, Jull GA. Muscle control-pain control: what exercises would you prescribe? Man Ther 1995;1:2–10.
59. Wilson JD, Dougherty CP, Ireland ML, et al. Core stability and its relationship to lower extremity function and injury. J Am Acad Orthop Surg 2005;13(5):316–25.
60. Hewett TE. ACL injury prevention programs. In: Hewett TE, Shultz SJ, Griffin LY, editors. Understanding and preventing non-contact ACL injuries. 1st edition. Champaign (IL): Human Kinetics; 2007. p. 57–60.
61. Alentorn-Geli E, Myer GD, Silvers HJ, et al. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 2: a review of prevention programs aimed to modify risk factors and to reduce injury rates. Knee Surg Sports Traumatol Arthrosc 2009;17:859–79.
62. Gillogly SD, Myers TH, Reinhold MM. Treatment of full-thickness chondral defects in the knee with autologous chondrocyte implantation. J Orthop Sports Phys Ther 2006;36(10):751–64.
63. Steadman JR, Miller BS, Karas SG, et al. The microfracture technique in the treatment of full-thickness chondral lesions of the knee in National League Football players. J Knee Surg 2003;16:83–6.
64. 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 Sports Med 2009;37(1):33–41.