What's New in the Management of Articular Cartilage Injuries in Athletes

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ABSTRACT

Aim: To review the literature on management of articular cartilage injuries in elite athletes with a focus on new developments.

Background: Articular cartilage injury is a common problem that can lead to significant pain and loss of function. This tissue has a poor healing capacity due to its avascular and aneural status. No treatment option has been completely successful in stimulating articular cartilage repair and regeneration. Such an injury in a professional athlete could turn out to be a performance- or a career-ending event. There is a dearth of evidence on the treatment of articular cartilage injuries in athletes. Hence, we reviewed available evidence on the management of articular cartilage injuries in professional athletes.

Materials and methods: A key word search was done on PubMed, Scopus, EMBASE, and Ovid Medline. After filtering, 89 articles were reviewed to extract available evidence on the subject.

Results: Overall there are few good-quality reports on the outcomes of cartilage repair and reconstruction techniques, specifically in professional athletes. Most reports are case series or reports. Most commonly involved areas include the femoral condyles, femoral heads, talus, humerus condyles, and the humeral head. Various treatment options have been tried and include chondroplasty, microfracture and its various modifications, bilayered autograft and allograft transplantation, and cell-based regenerative techniques (platelet-rich plasma, autologous cultured chondrocytes, and mesenchymal cells).

Conclusion: While most treatment methods have produced good results in the short- and mid-term, little good-quality evidence is available on their long-term results. The newer techniques such as tissue engineering methods, 3D bioprinting, and gene therapy appear to be promising. But these are still in preclinical state and are likely to pave way to better treatment options in the future.

Clinical significance: Elite athletes are a challenging group of patients who require exacting techniques, more demanding than the general population, to restore their function and return to play at same level. Current available techniques restore their function to a large extent, but outcomes may be improved. Cartilage restoration techniques are evolving, and newer techniques are developing to improve outcomes.

Keywords: Articular cartilage injuries in athletes, Elite athlete injuries, Narrative review articular cartilage injuries, Professional athlete cartilage injuries.

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INTRODUCTION

Articular cartilage (AC) is a nonvascular tissue with low potential for regeneration and repair. Hence, if not treated well and on time, it often leads to premature onset of osteoarthritis (OA). Injury to this delicate tissue is difficult to detect, and efforts are underway to develop modalities to diagnose and treat these injuries early. Management of these injuries as a result began in earnest after magnetic resonance (MR) techniques were developed for better visualization of the AC. Research and publications in this field are growing rapidly in the last 10 years.1 Elite athletes have high demand in their sporting activities necessitating a near-perfect AC, and an injury predisposes them to high chances of having an AC injury. Hence, it requires better healing methods to be able to withstand repetitive loads after the repair or regeneration of AC.

In this review, we look at the developments in the diagnosis and management of these injuries in elite athletes, with special focus on the advances in the last decade. We have also analyzed the pattern of articular injuries related to various sports and joints.

MATERIALS AND METHODS

Search strategies used for collecting citations on August 2, 2020, filter used was for the last 15 years from 2006 to 2019 (Table 1).

Combining all, and excluding duplications, we obtained 89 citations for which the full texts were reviewed.

Basic Science

Anatomy and Biomechanics

Articular cartilage is aneural, avascular, and alymphatic. It is made up of hyaline cartilage consisting of chondrocytes sparsely interspersed in a dense extracellular matrix of type II collagen, proteoglycans, noncollagenous proteins, glycoproteins, and 65...
Articular Cartilage Injuries in Elite Athletes

Table 1: Results of keyword search in various search engines

| Database     | Strategy                                                                 | No. of citations |
|--------------|--------------------------------------------------------------------------|------------------|
| Pubmed       | ("articular Cartilage") AND (Injur*)) AND (Elite Athlete OR Olympian OR Professional athlete) | 52               |
| Pubmed       | ("articular Cartilage" OR Chondral OR "Cartilage defect") AND (Injur*)) AND (Elite Athlete OR Olympian OR Professional athlete) | 94               |
| Pubmed       | ("articular Cartilage" OR Chondral OR "Cartilage defect") AND (Injur*)) AND (Elite Athlete OR Olympian OR Professional athlete) | 95               |
| Scopus       | ("articular Cartilage" OR Chondral OR "Cartilage defect") AND (Injur*)) AND (Elite Athlete OR Olympian OR Professional athlete) | 32               |
| Embase       | ("articular Cartilage" OR Chondral OR "Cartilage defect") AND (Injur*)) AND (Elite Athlete OR Olympian OR Professional athlete) | 11               |
| Ovid         | ("articular Cartilage" OR Chondral OR "Cartilage defect") AND (Injur*)) AND (Elite Athlete OR Olympian OR Professional athlete) | 4                |
| Medline R    | ("articular Cartilage") AND (Injur*)) AND (Elite Athlete OR Olympian OR Professional athlete) |                  |

The intrinsic arrangement and properties of tissue of AC are not conducive for early and full recovery after injury. Repair of AC depends on the depth of injury. Any injury occurring to the top three layers of the AC does not heal and remain as fissures or softening depending on the site of injury. When the injury involves the subchondral bone, the injured site gets filled with subchondral marrow blood and tends to heal by formation of fibrocartilage which contains primarily type I collagen.

There is evidence that moderate exercise maintains a healthy cartilage by an increase in the stiffness of the cartilage and proteoglycan synthesis. However, increased intensity of exercise as seen in elite athletes does not proportionally increase the AC content.

Imaging

Knee imaging should include the following radiographs: a standard weight-bearing anteroposterior view, a 45° weight-bearing posteroanterior view (WBPA), a lateral view, and a skyline or Merchant’s view. The 45° WBPA view detects osteochondral defects and early OA changes present in the weight-bearing portion of the femoral condyles. Outline of the subchondral bone of the femoral cortex should be carefully scrutinized to detect such defects.

Any suspicion of malalignment should lead to weight-bearing full-length alignment views of the lower limbs. Where available, EOS imaging of the limbs is useful for imaging and assessment of alignment with low radiation dose exposure. The knee joint should be checked for mechanical axis deviations in both sagittal and coronal planes. Where full length weight bearing radiographs are not available, CT scanograms may be utilized to study coronal, sagittal, and rotational profiles of the lower limbs.

Exciting developments have materialized in imaging of the AC. Quantitative and qualitative assessment of the AC is possible using recently developed MRI protocols. Different protocols have been developed to assess each component of the AC. DIGEMRIC scan assesses the proteoglycan content of the AC quantitatively, whereas T2 mapping can assess the collagen content and orientation. Based on the findings of these, irreversibly damaged cartilage or “at-risk” cartilage can be detected.

Edwards et al. confirmed the relatively poor diagnostic yield of MRI in the evaluation of cartilage abnormalities of the hip. Gadolinium-enhanced MR arthrography of the hip has shown better sensitivity and specificity at 95% and 88%, respectively. The more recent cartilage-sensitive MRI methods obviate the need for intra-articular gadolinium for detection of chondral lesions of the hip.

Future imaging studies should identify more clearly the persons and joint regions that are “at risk” in addition to identifying irreversible changes that have already happened. When such scans identify areas at risk of irreversible damage, steps could be taken to protect the AC from further damage, or strategies could be developed to reverse the changes and get the athlete back to high level of professional activity. This, however, currently applies to degeneration changes and may not apply to actual injury to the AC.

Natural History and Treatment

Damage to the superficial layer of AC leads to increased permeability of the matrix and cessation of matrix synthesis by chondrocyte apoptosis, leading to damage of AC by repeated loading and eventually leading to osteoarthritis. Increased pressure within the
matrix and over the chondrocytes also inhibits matrix synthesized by the chondrocytes. 3

Athletes with AC injuries participating in high-demand pivoting sports have a 4.4 to 5.3 times relative risk of developing knee OA. 10 Hence, it is important that these lesions are treated to reduce this risk.

**DISCUSSION**

The knee was the most studied joint in terms of AC injuries. Evidence of AC injuries in other joints have been limited to case reports or short case series.

**Knee Joint**

It is clear from the literature on football players that the incidence of OA changes in the knee, and total knee replacement (TKR) is high among professional and elite players compared to the normal population. 11 In the presence of meniscal injury or AC injury, this incidence further increased significantly. 1

There is extensive literature available on OA and injuries to the knee in footballers, whereas such information is scanty for the other sports perhaps due to the fact that football is the most popular sport in the world, and a major proportion of athletes play this sport.

While McDermott and Freyne (1983) 12 reported higher incidence of OA changes in the knees of runners, other studies have refuted these findings. Long-distance running as in marathon did not cause MRI-detectable adverse changes in the AC of the knees in recreational and semi-professional athletes who ran at least 3000 km annually in a study by Hofmann et al. 13 They had excluded runners who had overuse injuries in the previous 6 months. It is not clear whether professional athletes will reflect similar changes or to what extent they develop adaptive changes. However, Lazzarini et al. 14 demonstrated bone edema around ankles in 16 of 20 cross-country runners on MRI. Other important factors that may contribute to development of changes in the AC include limb malalignment and foot deformities.

Patellofemoral joint appears to bear the brunt of loading in basketball players. Among professional basketball players, AC lesions were found by MRI in 47.5% of the knees (Kaplan 2005) 15 in asymptomatic athletes. The most common locations were patella (35%), trochlear groove (25%), medial femoral condyle (10%), lateral tibial plateau (5%), and lateral femoral condyle (2.5%). Majority were found to be grade II lesions based on a modified Outerbridge’s classification.

Hirshorn et al. 16 studied at-risk knees in elite college football players being invited to attend the US National Football League Scouting Combine and found full-thickness chondral injuries in 20.1% of all players with involvement of the medial compartment, lateral compartment, patellofemoral compartment, or a combination of these in decreasing order of incidence. Higher body mass index (BMI) and body weight being a linebacker were risk factors for knee cartilage damage.

Among skiers, Noyes et al. 17,18 found 40 to 70% of ACL injuries were associated with AC injuries. Of these injuries, 74% occurred in the lateral compartment in skiers.

Ballet dancers do not appear to have an increased risk of AC injuries compared to nondancing athletes. 19 But in this group of athletes, OA changes were noted commonly in the medial femoral condyle with bone marrow changes in the lateral condyle. 20 An unusual lesion of subchondral intra-articular impaction fracture was reported among weightlifters from Poland in the posterosuperior portion of the nonweight-bearing part of the medial femoral condyle. This was associated with thickening or fissuring/chondral flap/perforation of the overlying AC. 21 Another unusual condition reported in the literature was the rapid chondrolysis occurring after partial lateral meniscectomy reported in a group of 10 cases. 22

Allograft transplantation has been used for the treatment of severe cartilage degeneration of the patella and the trochlea after three failed arthroscopic debridement in a professional basketball player. The player went on to play basketball at a high level. 23 Treatment should be goal oriented with an effort to achieve long-term pain relief and return to sufficient physical activity rather than to effect temporary pain relief. It is a relief that condyle-specific and anteroposterior matching allografts are not necessary to provide good outcomes. 24,25 The availability of cell-based regeneration techniques also allows for definitive treatment of large cartilage lesions in these high-demand patients.

**ACL Tears and AC Injuries**

ACL and meniscal injuries were the commonest injuries in elite athletes. 11 Progress of chondral lesions was found to be severe when associated with ACL injuries in skiers compared to other sports. 18 A gradual decline in the athletic activity has been reported if the AC defects are left untreated. 9

Cartilage injury in the ACL-deficient knee can result from (1) primary damage to the articular cartilage, meniscus, and ligament; (2) secondary traumatic injuries from recurrent instability; or (3) chronic injury secondary to alterations in the biomechanics of the knee. 26 The posterior horn of the medial meniscus works along with the ACL in preventing anterior displacement of the tibia. Hence, loss of the posterior horn further increases the shear stresses on the cartilage leading to damage and loss. 27

Various factors appear to influence the onset of cartilage loss and OA in the ACL-deficient knee. Acute meniscal and chondral lesions and release of cytokines, including interleukin 6 and 8, tumor necrosis factor, and keratin sulfate, can have direct detrimental effects on the AC. Certain other factors have indirectly led to increasing cartilage loss and OA and include a higher tibial slope, genu recurvatum, genu varum, morbid obesity, high-intensity physical activity, younger age at injury, delay to treatment, associated ligament injuries, and iatrogenic factors (use of synthetic grafts and partial meniscectomy). 26

Elite skiers sustained lateral compartment AC injuries along with ACL injury. 18 They sustained more concomitant injuries than footballer players. 28

Shelbourne and Gray 29 found more AC lesions in association with a meniscal tear (34.5%) when compared to those knees without a meniscal tear (10.3%) in patients undergoing ACLR. In fact, 40 to 50% of meniscal injuries also have AC injuries. 30 The rate of grade III or higher lesion in this study was 21%. Thirty-eight percent of ACL injuries in elite athletes needed surgery for chondral injuries. 18

Findings from the MOON 11,32 and MARS 33 study groups show that patients undergoing revision ACL reconstruction were found to have more AC lesions (43%) compared to those undergoing ACLR for the first time (17%). Moreover, higher grade lesions (modified Outerbridge’s classification) were more commonly found during revision ACLR (64%) in comparison to during primary ACLR (28%).

**Hip**

Increased torsional forces and the repetitive loading of the hip in the elite athlete subjects the labrum to tensile and compressive forces. Subsequent labral tearing and/or chondral injury when
left untreated leads to progressive degeneration of the AC. Ferguson et al. demonstrated that the labrum had an important sealing function in the hip joint that limited fluid expression from the joint space and protected the cartilage layers of the hip. Labral tears significantly increased cartilage surface consolidation as well as contact pressure of the femoral head against the acetabulum.

Magnetic resonance imaging has variable sensitivity and specificity for the detection of cartilage defects (58–83% and 50–100%, respectively). MRI orthography had similar sensitivity (62.7%) in identifying AC injuries in these patients. Subsequently, arthroscopy of the hip joint helps to address the impingement and the labral and AC injuries.

Bilateral hip arthroscopy has been used to treat persisting pain resulting from femoroacetabular impingement (FAI) with associated labral tear and cartilage injury. FAI has been known to include debridement and transarticular drilling, fixation of the fragment, and autologous osteochondral mosaicplasty. There is available literature on adolescent athletes but no report exclusively on elite athletes.

Michelli et al. reviewed literature on AC repair in adolescent athletes prior to 2006 and concluded that where possible primary repair is recommended and where primary repair was not possible or in large lesions, the authors recommend secondary repair techniques using marrow stimulation, AC, or autologous osteochondral grafting.

The treatment options for management of OCD of the elbow include debridement and transarticular drilling, fixation of the fragment, and autologous osteochondral mosaicplasty. There is available literature on adolescent athletes but no report exclusively on elite athletes.

Management of AC Injuries in Athletes

Management options may be broadly divided into categories that form a spectrum from simpler, less expensive techniques to more complex and expensive techniques. These have been grouped into palliative, reparative, and restorative techniques. Palliative procedure are done in very small lesions and in low physical demand patients and do not form part of this review. These include debridement/chondroplasty. Reparative techniques include marrow stimulation techniques (microfracture and microdrilling) and restorative techniques such as osteochondral transplantation techniques and cell-based repair techniques. Before undertaking cartilage repair/regeneration techniques, it is important that malalignment of the limb, instability of the joint, and, in the case of the knee, meniscal pathology, are ruled out or managed, since presence of these adversely influence the outcome or cartilage repair/regeneration. There is consensus that AC defects less than 2 cm² may be treated using microfracture technique. Larger defects require other techniques.

Chondroplasty/Debridement

Chondroplasty is recommended for partial thickness AC lesions with chondral flaps to remove the flap and leave the underlying deeper layers of the AC intact. It is recommended that this procedure be done using biter and mechanical shavers and avoid using thermal ablation due to the potential of damage to the chondrocytes due to increased temperature. Microfracture techniques have been recommended, since they can create a uniform gliding surface of the AC and less chondrocyte damage.

Microfracture

Microfracture involves creating a series of 2 mm holes using a custom-made awl in the subchondral bone in the bed of the full thickness AC defect after preparation. The hole extends into the marrow to let stem cell access to the defect filled with blood clot, ultimately forming fibrocartilage in time. The disadvantages of this technique are fracture of the intervening bridge of bone, collapse of the segment microfractured, especially when done in weight bearing portions, and poorer results when compared to other techniques.
Mithoefer and Steadman\textsuperscript{28} performed a review of literature of microfracture outcomes in 2012 and found a gradual decline in the results of microfracture, worse so in athletes who had poor repair cartilage morphology and fill after this technique. The average return to play rate was 66%. Factors that were found to be favorably affecting return to play after microfracture were younger age, size of defect less than 2 cm\textsuperscript{2}, rapid diagnosis, access to postoperative rehabilitation (protocol depended on the location of the defect), socioeconomic factors, and motivation of the athlete. Unfavorable factors are delayed surgery and prolonged preoperative intervals (5-fold better return to play if surgery was done before 12 months—67% vs 14%).\textsuperscript{29} One-third of these players required other procedures to ligaments or meniscus. Athletes with prior surgeries fared worse (33%) compared to first time surgery for microfracture (86%) in order to return to play.\textsuperscript{54}

Subchondral bone overgrowth after microfracture can lead to thinning of the regenerated cartilage and lead to biomechanical disadvantages and reduced outcomes in the long-term. Its frequency has been reported to be between 10 and 90% and thought to occur between 6 months and 12 months after the procedure. Risk factors for its development have been identified to be high BMI, defects over lateral femoral condyle, and aggressive debridement of the cartilage.\textsuperscript{55} Results of microfracture in individual sports are given in Table 2.

Augmentation of microfracture using scaffolds has been reported. AMIC (Table 3) was presented in a case report to show successful return to professional football 10 months after the procedure.\textsuperscript{64} In a systematic review Maioregen (Table 3), significant clinical improvement had been reported in almost all studies for up to 5 years after the procedure. Among a total of 500 lesions with average size of $3.6 \pm 0.85 \text{ cm}^2$, and failure rate was 3.39%.\textsuperscript{60} They conclude that the quality of evidence is low, and this technique is not superior to current cartilage restoration techniques.

**Micro-drilling/Pridie Drilling**

Micro-drilling was developed to counter the disadvantage of drilling that caused bone necrosis due to heat around the drill hole with a bigger diameter drill bit. Chen et al.\textsuperscript{72} demonstrated that microfracture using an awl tends to impact the subchondral bone potentially sealing off the hole from the underlying marrow, while micro-drilling using a microdrill does not produce this effect. It was also demonstrated that there is not heat necrosis of bone.

### Table 2: Microfracture results in individual sports players

| Authors            | Year | Follow-up | Results of microfracture |
|--------------------|------|-----------|--------------------------|
| Steadman et al.\textsuperscript{56} | 2014 | 77 months (24–255 months) | Of these 95% returned to competitive skiing. At 54 months, 66% had good to excellent results. Younger age and smaller lesions had better outcomes. |
| Cerynik et al.\textsuperscript{57} | 2009 | 7.5 months | Among professional basketball players, 79% returned to sport after a mean of 7.5 months after microfracture |
| Riyami et al.\textsuperscript{58} | 2009 | 83.3% players resume full training within 5–7 months after microfracture of full-thickness defects in weight-bearing regions of the knee. Second-look arthroscopy score proved to have stronger strength of association with function score than MRI score and is considered the gold standard for assessment of healing. |
| Kreuz et al.\textsuperscript{59} | 2006 | 36 months | Showed that the fill in the defect after microfracture was better and there was a better overall score in young patients <40 years at 36 months after microfracture in defects of femur and tibia. |

### Table 3: Augmentation techniques to improve results used in literature for first- and second-generation microfracture

| Technique | Description |
|-----------|-------------|
| BMP7 and BMP4 | Induce chondrogenic marker gene expression to produce type II collagen qualitatively and quantitatively |
| +Growth factors\textsuperscript{60} | by modulating negative effect of cytokines like IL-1 on repair tissue. |
| +Modulators of cytokines\textsuperscript{60} | Scaffolds reduce chances of clot displacement |
| +3D scaffolds\textsuperscript{60} | Polyglycolic acid (PGA)/hyaluronan |
| +3D scaffolds seeded with chondrocytes | Chitosan–glycerol phosphate (BST-CarGel\textsuperscript{TM}) |
| +Hyaluronic acid augmentation\textsuperscript{60} | Chondroitin sulfate/hydrogel (ChonDux\textsuperscript{TM}) |
| +Polyethylene glycol (PEG) polymer hydrogel | Polyethylene glycol (PEG) polymer hydrogel |
| BST Cargel\textsuperscript{67} | Scaffold of collagen 1, 2, and 3 seeded with cultured chondrocytes to guide chondroinduction and reduce clot displacement\textsuperscript{61,62} |
| AMIC\textsuperscript{64} | Defect cover consists of a resorbable polymer felt and sodium hyaluronan to induce hemostasis and to protect the underlying tissue.\textsuperscript{63} |
| AMIC (autologous matrix-induced chondrogenesis)\textsuperscript{64} | AMIC (autologous matrix-induced chondrogenesis) combines microfracture, exogenous collagen scaffolds with or without fibrin glue. (AMICGeistlich, Princeton, New Jersey, USA) was presented in a case report to show successful return to professional football 10 months after the procedure.\textsuperscript{64} Multiple other studies have been published on this technique with upto 76.2% excellent or satisfactory results but none exclusively on elite athletes.\textsuperscript{65,66} |
| BST-argel, Piramal Healthcare, Laval, Canada | Combination of micronized allograft chondrons and autologous growth factors was applied with good result at final follow-up at 15 months. However, evaluation was purely clinical.\textsuperscript{68} No arthroscopic or imaging follow-up was given at final follow-up |

Contd…
**Contd…**

| First generation | Classical microfracture technique may be augmented by other steps |
|------------------|---------------------------------------------------------------|
| +MaioRegen⁷⁹     | MaioRegen (Fin-Ceramica Faenza SpA, Faenza RA, Italy) is a nanostructured biomimetic and bioresorbable implant with a porous composite structure with a three-layered anatomy similar to the osteochondral anatomy |
| +ACIC⁷⁰          | Autologous Collagen-induced Chondrogenesis. Microfracture + Fibrin gel mixed with MSC derived Atelocollagen (purified of type I collagen extracted from porcine dermis and treated to remove immunogenicity). No studies on elite athletes. |

**Second generation**

| + Growth factors | to improve qualitatively and quantitatively the chondrogenic differentiation in the repair cartilage |
|------------------|------------------------------------------------------------------|
| +Stem cells        | BMAC/Adipose derived stem cells                                   |
| +Scaffolds⁷¹       | Chitosan, collagen membranes, hyaluronan-based scaffolds, miniced or micronized allogeneic cartilage |

**Mosaicplasty/Osteoarticular Transplantation (OAT)**

This was popularized by Hangody⁷³ in 2003. The technique involves harvesting cylindrical osteochondral grafts from limited weight-bearing areas, most commonly in the knee joint and transferring them by press fit into AC defects in weight-bearing areas of the joint. The outcomes with this technique were good with 95% good to excellent results and 84 to 94% good to excellent follow-up MRI ratings.⁷⁴,⁷⁵ Results of mosaicplasty appear to be better among elite athletes with good to excellent results reported in 86 to 92% cases in elite athletes⁷⁶,⁷⁷ compared to 78.6% in a mixed population.⁷⁸ The only location with lower results in elite athletes is in the patellofemoral joint with 74% good to excellent outcome.⁷⁷ When results were classified according to the site of defect, good to excellent results were seen in 91% femoral, 86% tibial, 74% patella femoral, and 92% talar mosaicplastics.⁷⁷ The disadvantage with this technique is the 5% incidence of patella femoral pain arising from the harvest site.⁷⁷

When comparing microfracture with OAT, the mean time to failure for microfracture was significantly shorter compared to OAT (4 years vs 8.4 years). When survival was compared between the groups, 80% survived 7 years and 60% for 15 years, whereas in the microfracture group, survival was less than 80% and 60% in 12 months and 3 years, respectively.⁷⁹ Similar results were echoed by Lynch et al. in their systematic review comparing microfracture with OAT with higher rate of return to sport and maintaining level of sport in OAT group and more reoperations and deterioration around 4 years in the microfracture group.⁸⁰ Comparison of OAT with ACI was inconclusive. However, after 10 years, failure rate was greater in OAT compared to ACI.⁸⁰

**Osteochondral Allograft Transplantation**

Osteochondral allografts have the advantage of avoiding donor site morbidity. Outcomes were good for the short-term. However, the results deteriorated over time with a survival of 95%, 80%, and 65% at 5, 10, and 15 years after transplantation, respectively.⁸¹ These results were not exclusive to elite athletes.

**Autologous Chondrocyte Implantation/Characterized Chondrocyte Implantation/Matrix-associated Chondrocyte Implantation**

Autologous chondrocyte implantation is a two-step process, where in step 1, an arthroscopy, is performed and cartilage is harvested from the knee and sent for ex vivo expansion of chondrocytes in cultures, and these cells are reimplanted in the defect after a period of 4 to 5 weeks. These cells are placed in a carrier or a medium to hold the cells in place within the defect. The success of this procedure depends on how stable the cells are held in the defect while cartilage matrix is synthesized by these cells.⁸² In some cultures, expansion of these cells leads to loss of chondrogenic capacity to produce type II collagen and results in fibrocartilage formation. Characterized chondrocyte implantation (CCI) was developed to avoid this loss of chondrogenic capacity to create a population of chondrocytes that express a marker profile (a gene score) that predicts the capacity to form hyaline-like cartilage consistently and reproducibly.⁸³ They are implanted beneath a periosteal flap covering the defect.

In a randomized controlled trial comparing microfracture not specifically for athletes, CCI showed superior structural outcome with long-term clinical benefit at 12 months⁸⁴ when compared to microfracture. Complications of this technique include arthralgia, hypertrophy of the cartilage, deep venous thrombosis, and fascia lata tendinitis.

Matrix-associated chondrocyte implantation uses biomatrix scaffold seeded with chondrocytes gives the advantages of less chondrocyte leakage, more uniform distribution of cells, and less graft hypertrophy. It may be done open or arthroscopically and better outcomes are reported in younger patients <30 years and athletes participating in higher level competitive sports.⁸⁵

**Recent Advances and Future Directions**

Apart from advances in microfracture which have been listed in that section, recent advances and future directions are pushing the barriers in each technique to improve results within the groups. They have been listed in Table 4 along with available evidence.

**Conclusion**

Imaging of AC injuries has seen major improvements in identifying and defining them at an early stage. Standard methods to treat AC injuries have been improved upon with promising results. Regenerative techniques such as ACI show promise in the young athlete and for larger lesions with good long-term outcomes. The newer techniques like tissue-engineering methods, 3D bioprinting, and gene therapy need more clinical studies to enter mainstream therapies. We call for more extensive analysis of outcomes of the various treatment methods for specific sporting professions. We recommend the installation of a National Sports Registry to encourage more data recording and analysis to guide treatment.
methods and improve future outcomes in this high-demand population.

Table 4: Recent advances

| S. no. | Treatment                                                                 | What is the evidence?                                                                 |
|-------|---------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| 1     | Platelet-rich plasma (PRP) (above-baseline concentration of platelets in plasma) | Pain and functional outcome scores improved at 6-month follow-up after intra-articular injection of PRP. Improvement is short-term. Pain scores and functional outcome scores worsened by 24 months after the procedure. |
| 2     | Bone marrow–derived MSCs (BMDSCs) (one-step cartilage reconstruction technique) | Treatment of full-thickness chondral defects of the knee with collagen matrix augmented with BMDSCs showed significant improvement in multiple clinical scores. Complete MRI filling of the defect was found in 80% of the patients. Comparison with MACI for patellofemoral lesions has shown comparable clinical results at two years follow-up. |
| 3     | Tissue engineering (two-stage technique)                                  | First stage: Cartilage harvest, chondrocyte culture and seeding in a scaffold (collagen gel, sponge construct or a 3D printed scaffold) and incubation in a bioreactor. Second stage: Implanting this 3D construct into the cartilage defect with the help of bioadhesive (e.g., fibrin glue). T2 mapping has shown hyaline-like healing of cartilage in 57%; good cartilage fill, peripheral integration and pain relief in 86% up to 2 years after implantation. (Neocartilage) Works by additive manufacturing. Multilayered osteochondral tissue construct is created by bioprinting MSCs with hyaluronic acid to mimic cartilage and MSCs on a polycaprolactone frame to mimic subchondral bone; promising results in rabbits. |
| 4     | 3D bioprinting of cartilage and subchondral bone                          | Synchronous printing of bioink with cells, layer-by-layer, in a scaffold-free fashion to mimic the cartilage with the subchondral bone. Works by additive manufacturing. Multilayered osteochondral tissue construct is created by bioprinting MSCs with hyaluronic acid to mimic cartilage and MSCs on a polycaprolactone frame to mimic subchondral bone; promising results in rabbits. |
| 5     | Gene therapy                                                              | Adenoviral-mediated transfection of cDNA encoding for TGF-b1, IGF-1, BMP-7 and BMP-2 shown to stimulate expression of cartilage-specific extracellular matrix and decreased chondrocyte dedifferentiation. Retrovirally transduced MSCs shown to enhance quality of cartilage repair tissue. Likely to emerge as an option for treating cartilage injuries in athletes. |

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