MENTORS IN ORTHOPEDICS

KNEE CARTILAGE REPAIR AN UPDATE

https://doi.org/10.71165/abi3-zre1

AUTHOR

Philippe Landreau - DXBone, Bone and Joint Excellence Center, Dubai, United Arab Emirates

SUMMARY

Background: Chondral and osteochondral defects of the knee present significant clinical challenges due to the limited intrinsic regenerative capacity of articular cartilage. These lesions often result from acute trauma or repetitive microtrauma and, if left untreated, increase the risk of secondary osteoarthritis, particularly in young and athletic populations.

Objective: This article provides a comprehensive update on current surgical techniques for knee cartilage repair, evaluating their methodologies, clinical outcomes, and comparative efficacy to guide orthopedic decision-making.

Key Points: Surgical interventions are categorized into palliative, reparative, substitutive, and regenerative approaches. Bone marrow stimulation via microfracture remains a common first-line treatment for small defects, though its reliance on fibrocartilage formation may lead to long-term clinical deterioration. Augmentation techniques using scaffolds, such as autologous matrix-induced chondrogenesis (AMIC), aim to stabilize the initial clot. Osteochondral autograft transfer (OAT) and allograft transplantation (OCA) provide immediate hyaline cartilage replacement, with OCA being preferred for larger defects. Autologous chondrocyte implantation (ACI) and its subsequent matrix-induced generations (MACI) offer regenerative potential, showing superior durability for extensive lesions compared to microfracture. Emerging one-stage techniques, including minced cartilage and mesenchymal stem cell applications, are currently under evaluation. Comparative data suggest that while short-term outcomes are often similar across techniques, OAT and ACI may offer more sustainable results and higher rates of return to sport for specific patient cohorts.

Conclusion: No single technique currently restores native hyaline cartilage perfectly. Treatment selection must be individualized based on patient age, activity level, and lesion characteristics, utilizing a structured algorithmic approach to optimize clinical outcomes.

KEYWORDS

Cartilage, Articular; Knee Joint; Orthopedic Procedures; Chondrocytes, Cultured; Transplantation, Autologous

INTRODUCTION

Chondral and osteochondral defects of the knee are common [Widuchowski]. They can be the consequence of an acute injury or following repetitive micro-traumas. Cartilage injuries can occur in conjunction with ligament and meniscus tears as well. They can impair the quality of life and increase the risk of developing degenerative joint disease over time. Cartilage has a very low potential for spontaneous repair, making chondral and osteochondral defects of the knee a difficult clinical challenge, particularly in young people and athletic population. Besides the conservative and non-operative treatment, different surgical techniques have been developed to address the focal cartilage defect. These techniques can be divided into palliative (chondroplasty and debridement), reparative (bone marrow stimulation), substitutive (osteochondral autograft, allograft or synthetic transfer) and regenerative (autologous chondrocyte implantation). The “ideal” procedure for the treatment of focal articular cartilage defect should restore normal hyaline cartilage through a minimally invasive approach, if possible in one stage, with minimum morbidity and low cost. Currently, this ideal technique does not exist but few procedures have shown some good short term results and there are some more recently developed techniques that look promising. This article is intended to provide an update on the current surgical techniques for knee cartilage repair and their results.

HISTORY OF ARTICULAR CARTILAGE RESTORATION

In 1743 William Hunter was the first to publish a paper on cartilage: “On the structure and diseases of articulating cartilages” in which he stated “An ulcerated cartilage is universally allowed to be a very troublesome disease... and that, when destroyed, it is not recovered” [Hunter].

In 1959 Pridie was the first to introduce a technique of subchondral drilling for the treatment of osteoarthritis [Pridie]. Ficat in 1979 described the “Spongialization” in which the cancellous bed was exposed [Ficat] and Johnson & al. described the “abrasion arthroplasty” [Johnson]. Later, in 1997, based on the same concept, Steadman described the arthroscopic marrow stimulation using what he called “microfracture" [Steadman]. Brittberg and Peterson [Brittberg] were the first to publish a case series of cell transplant with autologous chondrocyte implantation (ACI) in 1994. Another technique was proposed by Hangody, the autologous osteochondral transfer (mosaicplasty) for the treatment of larger lesions with multiple small osteochondral cylinder plugs [Hangody 2003].

ARTICULAR CARTILAGE SURGICAL TECHNIQUES

Besides the chondroplasty and debridement, which are only palliative techniques, different procedures can be performed to restore the joint congruence with the same goal which is to induce hyaline cartilage (Figure 1).

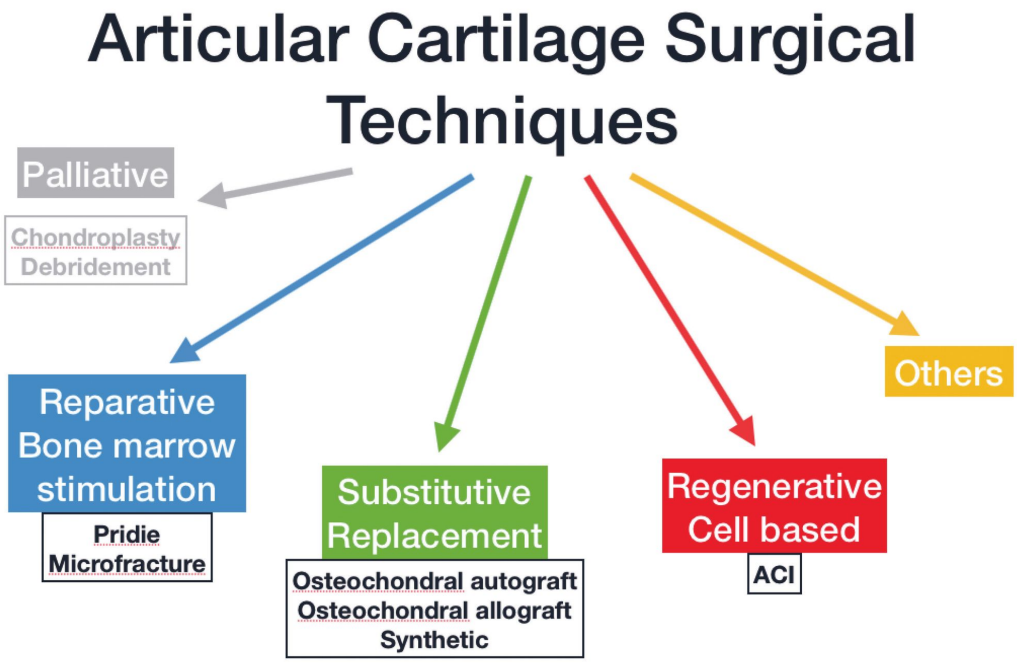


Figure 1: The different articular cartilage surgical techniques.

Bone marrow stimulation using Pridie drilling or the more recent microfracture (MF), attempts to provoke cartilage repair. Mosaicplasty and the osteochondral allografting substitute the defect with osteochondral unit and Autologous chondrocyte implantation aims at cartilage regeneration. All of these techniques have shown favourable results in clinical outcomes at short term follow up but only few studies have compared the long term results of the different techniques. It is difficult to state in 2018 which techniques will be the best as the indication and the result depend on multiple factors such as location and size of the defect, patient's age and demand, economic, legal and geographic issues. Nevertheless, after 20 years of cartilage repair and restoration, a guide and an algorithm for treatment, that orthopaedic surgeons can practically use in their daily decision making, can be defined.

Bone Marrow Stimulation

Nowadays, the microfracture procedure is the most frequent technique performed for bone marrow stimulation. The assumption is that multipotent stem cells, from bone marrow, can reach the damaged area by microfracture gap. This technique, popularized by Steadman in 1997 [Steadman], used arthroscopic awl to penetrate the subchondral bone in a controlled pattern resulting in release of blood and mesenchymal cells capable of repairing the cartilage (Figure 2).

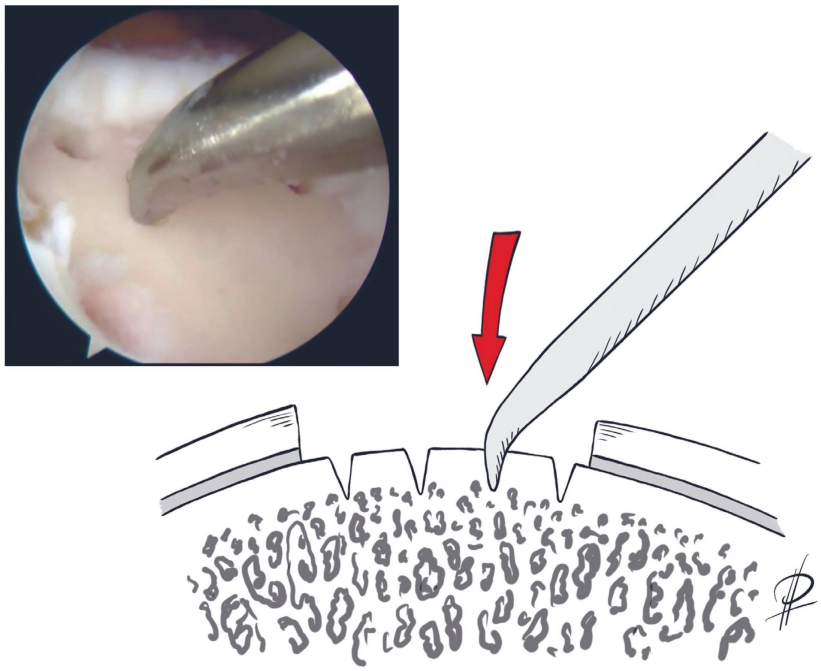


Figure 2: Microfracture: The assumption is that multipotent stem cells, from bone marrow, can reach the damaged area by microfracture gap.

Several studies have shown that the use of microfracture for the treatment of small lesions in patients with low post-operative demands, has resulted in good clinical outcomes at short term follow up. However, osteoarthritis and treatment failures were observed at a later post-operative period of 5 to 10 years [Goyal]. While this technique has some advantage as it is an inexpensive and a single stage arthroscopic procedure, it does have disadvantages as well. Microfracture technique relies on the differentiation of primitive mesenchymal cells to repair the cartilage but this leads to the production of fibrocartilage and not hyaline cartilage. It cannot restore the bone and some intra-lesional osteophytes may form. In addition, it has been suggested that when an ACI is performed after a failed microfracture procedure, the rate of failure could be 3 times more than non-treated defects due to violation of the subchondral bone. This work suggests that microfracture performed for large chondral defects

may compromise further revision with ACI and therefore should be decided upon cautiously [Minas].

Microfracture and Augmentation

In order to improve the efficiency of the microfracture, augmentation by using scaffold has been proposed. The initial term proposed for this concept was Autologous matrix-induced chondrogenesis (AMIC). It combines microfracture surgery with application of scaffold in order to physically stabilise the clot and enhance the marrow-derived repair [Benthien] (Figure 3).

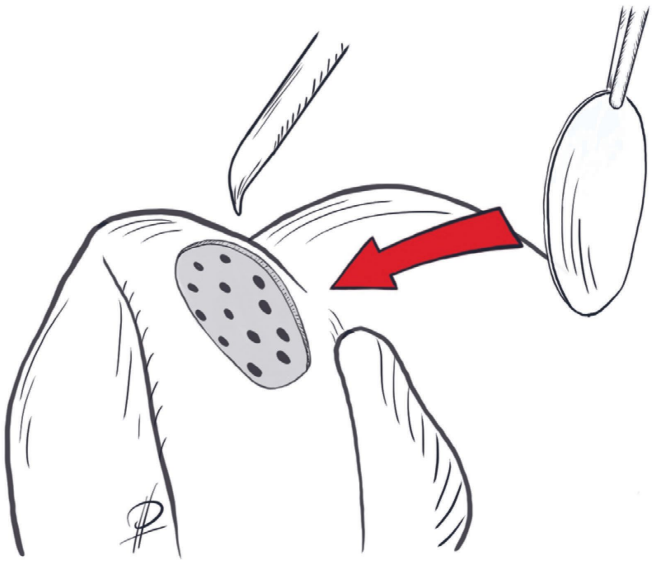


Figure 3: Autologous matrix-induced chondrogenesis (AMIC): Combination of micro fracture and scaffold.

Variable scaffolds are used and range from a true physical membrane or a biphasic liquid hydrogel that congeals in situ. These scaffolds can also be combined with different additional substances such as growth factors or bone marrow concentrate [Enea, Siclari].

The three main physical membrane scaffolds reported in the literature for AMIC are ChondroGuide, Hyalofast and Chondrotissue.

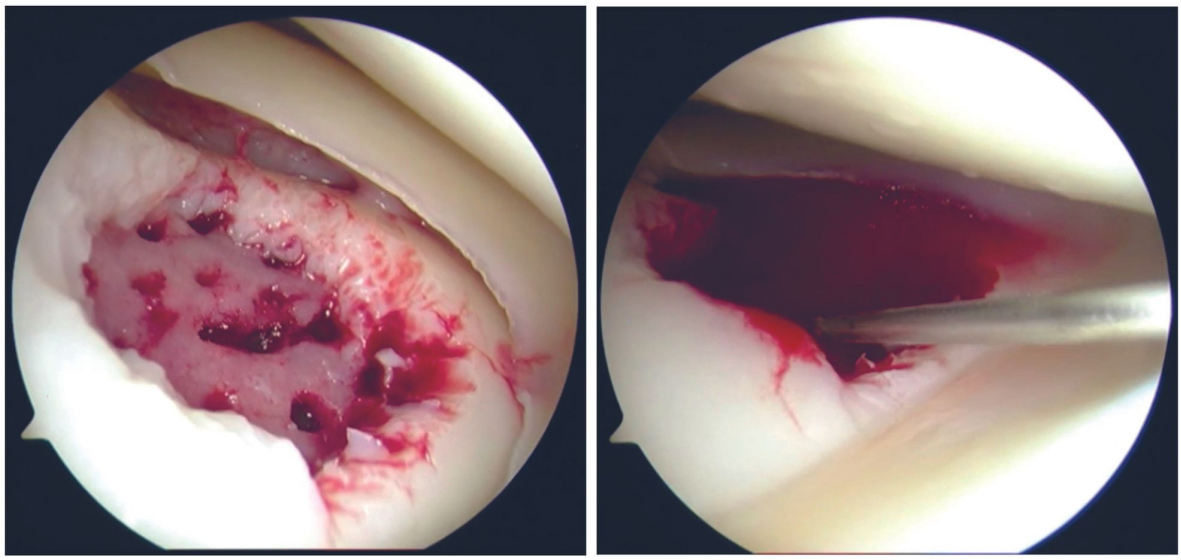
ChondroGuide is a porcine-derived type I/III collagen membrane, a protein-based natural bilayer collagen matrix that exists as a porous cell adhesive and a smooth cell occlusive layer. The cell adhesive layer ensures the mesenchymal stem cells (MSCs) are attached to the collagen fibres. The second cell occlusive nonporous layer makes sure that the super clot remains in the defect [Lee].

Chondrotissue is an absorbable polyglycolic acid textile treated with hyaluronan, acting as a sponge, holding the clot and the MSCs within the defect.

Hyalofast is an absorbable semi-synthetic derivative of hyaluronic acid used for entrapment of MSCs, inducing them from the bone marrow to differentiate along the chondrogenic lineage.

The short term clinical outcomes and MRI results of the augmented microfracture are predominantly positive in short term follow up and comparable to other cell-based methods [Krych 2016, Lee]. But studies conducted on longer than 24 months follow up, report controversial conclusions which questions the durability of the microfracture technique [Krych 2016]. Recently, Gao et al., in a systematic review on AMIC, concluded that there is a paucity of high-quality, randomized controlled studies testing the AMIC technique versus established procedures such as microfracture orACI. Therefore, they conclude that the evidence is insufficient to recommend specific indications for AMIC [Gao].

BST-CarGel is one of the scaffold gels that are used for enhancing cartilage regeneration. This chitosan polymer is mixed with the patient's own blood and the hydrogel is applied onto the microfractured area. The polymer's role is to physically stabilise the blood clot in the cartilage defect, provide matrix to strengthen the clot, prevent retraction and increase adhesiveness (Figure 4).



A B

Figure 4: BST-Cargel procedure. Microfracture on a lateral tibial plateau cartilage defect (A) followed by injection of the gel (B).

The intention is to improve the overall durability of the repair and prolong the effect of the cells and tissue factors derived from the blood clot [Steinwachs]. A randomized comparative study evaluating BST-CarGel and microfracture alone, in repairing focal grade III and IV cartilage lesions of the femoral condyle have shown, that at 5 years follow up, BST-CarGel treatment resulted in sustained and significantly superior repair tissue quantity and quality over microfracture alone. However, subjective outcomes

were similar between the two groups [Stanish].

CARTILAGE TRANSPLANTATION AND SUBSTITUTION

Osteochondral Autograft Transfer

With Osteochondral Autograft Transfer (OAT), the defects are filled immediately in a one-stage procedure with osteochondral cylinders, harvested from the trochlea and intercondylar notch through perpendicular access to the cartilage surface (Figure 5). This arthroscopic, mini open technique, allows the donor's osteochondral cylinder to be flushed in order to re-create the normal articular contour and contact pressures in the pathological area. The advantage is to immediately replace the defect by mature hyaline articular cartilage with the ostechondral unit. The main limitations are the ability to treat large lesions [Hangody 2003, Gudas].

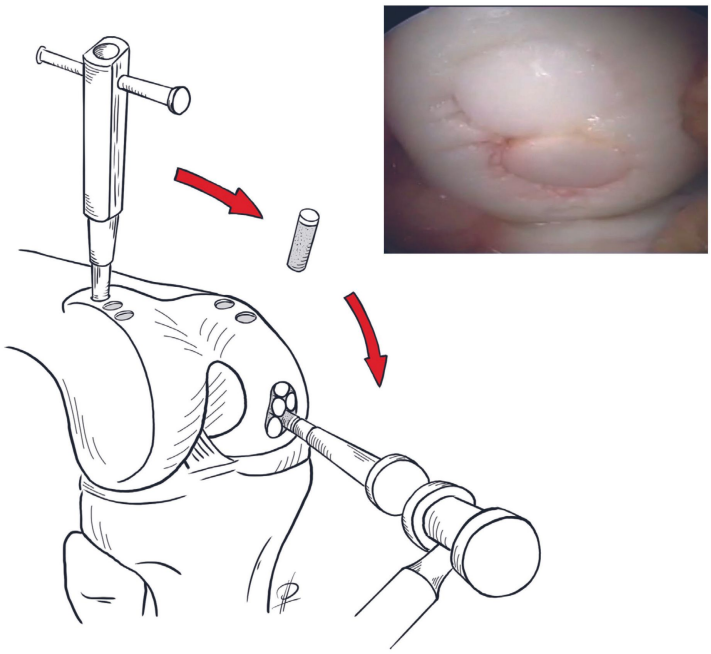


Figure 5: Osteochondral autograft transplantation.

The literature has reported good to excellent results in 70% to 90% of the patients undergoing mosaicplasty for a femoral condyle cartilage defect 10 years post operation [Gudas, Hangody 2008, Solheim]. Some histological analyses have shown high rate of survival of the transferred chondrocytes and chondral matrix integration. The outcome varies depending on several factors such as age and size of the lesion. Failure rate increases in patients older than 40 years and in patients with defect size greater than 3 cm2.

Osteochondral Allograft Transplantation

The osteochondral allograft transplantation (OCA) is a single stage technique used for large osteochondral defects. Like in osteochondral autograft, a cylinder plug is harvested but from fresh cadaver donor matching the size, shape and location of the osteochondral defect (Figure 6).

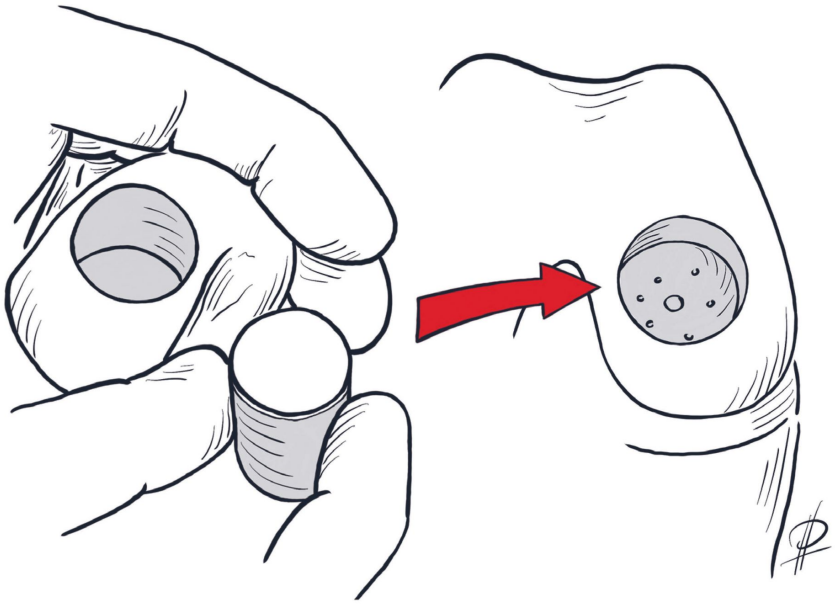


Figure 6: Osteochondral allograft transplantation.

The aim is to achieve gradual replacement of the cadaveric bone by the host bone, keeping the viability of the hyaline cartilage intact. The advantage of this technique is that it allows treatment of large and very large defects in a single stage procedure, transferring hyaline cartilage with underlying bone unit. Its disadvantages are cost, potential risk of infection, immune reaction and limited graft availability; the fresh OCA stored at physiologic temperature having the highest level of chondrocyte viability [Geraghty]. Several studies have shown consistent good results with graft survivorship around 80% at 10 years and around 65% at 20 years [Levy, Familiari].

Synthetic Cell-Free Substitution

A variety of biomaterial scaffolds have been developed to substitute the cartilage and its subchondral bone structure. They have the advantage that the off-the-shelf product is used to fill the defect in a single stage procedure with no donor site morbidity. These materials are biodegradable and provide a temporary protection to the repair site, allowing mesenchymal cells to seed the defect and ultimately produce hyaline cartilage and reconstruct the underlying bone at the same time. These implants are usually biphasic, intended to restore the two layers, cartilage and subchondral bone.

TruFit

TruFit has been proposed a few years ago. It is a synthetic scaffold with 3mm polylactic-co-glycolic acid (for the cartilage layer) and calcium sulphate trabecular network similar to the cancellous bone. Studies have shown controversial results, with some acceptable results and some other showing significant failure and persistence of symptoms [Bugelli, Gelber].

MaioRegen

The MaioRegen scaffold seems to have a better success. It is a multi-layered biomaterial consisting of collagen type I and magnesium-hydroxyapatite (Figure 7).

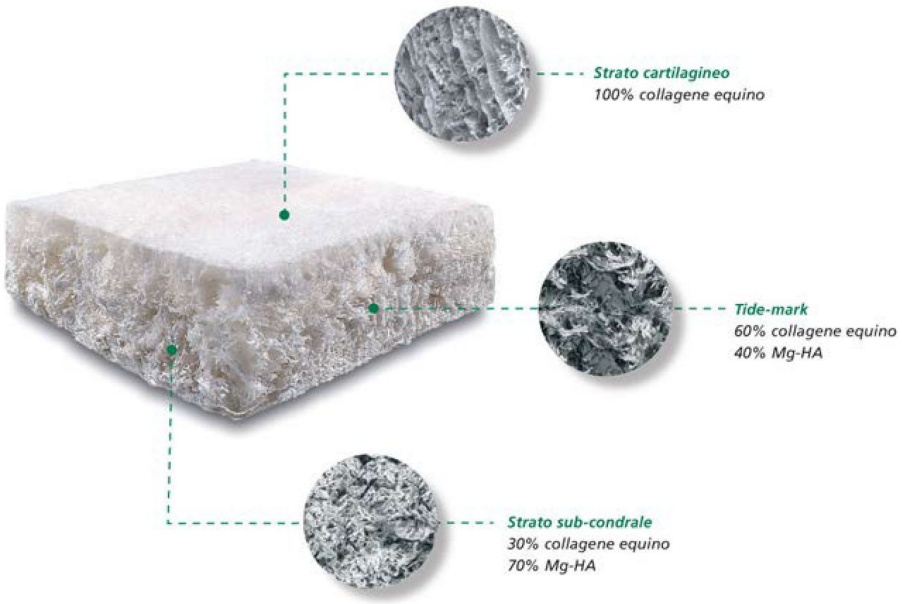


Figure 7: MaioRegen.

Promising results have been shown at short and mid-term follow up. However, there were some failed cases and more studies are needed to further confirm these results in the future [Kon 2014].

Regeneration techniques with cell-based procedures

These procedures can be performed in one or two stages. Autograft chondrocyte, allograft chondrocyte or stem cells can be used.

The classic autologous chondrocyte implantation (ACI) was performed for the first time by Peterson and Brittberg in the eighties and the first results were published in 1994 [Brittberg]. This technique is a two-stage procedure (Figure 8).

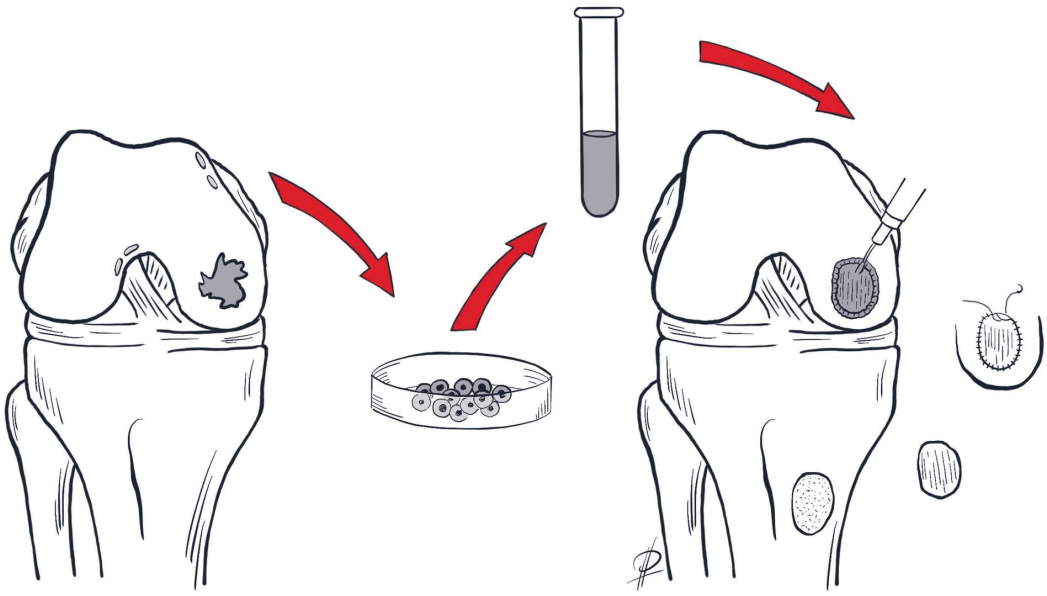


Figure 8: Autologous chondrocyte implantation (ACI), first generation.

In the first stage, arthroscopy is performed for cartilage harvesting and then autologous chondrocytes are cultured by in-vitro multiplication in the laboratory. During the second stage, a patch of periosteum is harvested locally from the tibia and sutured to the edges of the cartilage loss. Then the culture of autologous chondrocytes is injected in the cavity before impermeabilisation with biological glue [Versier]. This technique has provided good long-term results [Peterson, Brittberg, Minas]. This first generation of ACI has been complicated by some graft failure, delamination and mainly hypertrophy of the graft. Later, second and third generation techniques have been developed. In the second generation, porcine collagen membrane replaced the periosteal flap in order to cover the graft. This technique significantly reduced the incidence of graft hypertrophy [Gomoll]. The third generation, matrix-induced ACI (MACI) technique was developed to improve the distribution and the stability of the graft by a scaffold. The culture of cells is seeded onto and within the matrix in the laboratory (Figure 9).

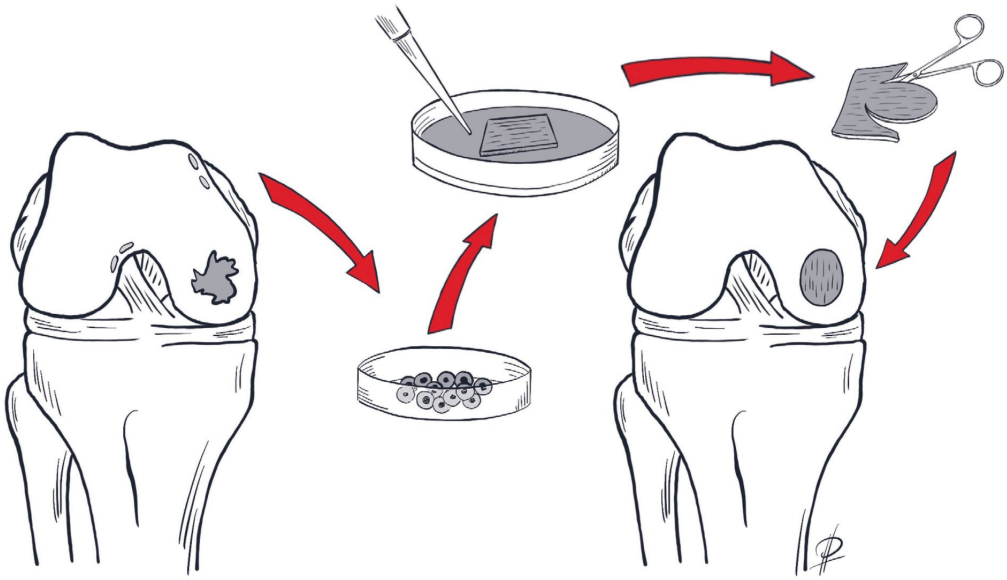


Figure 9: Matrix-induced ACI (MACI).

The second stage technique is simplified and can be performed with more limited approach. Multiple types of matrix have been used, synthetic (carbon, polylactic or polyglycolid acid), proteic (collagen, fibrin, gelatine) or polysacharid (alginate, agarose and hyaluronic acid) [Versier]. Some of these scaffolds are used either in ACI or combined with the microfracture.

Recently, a new ACI technique from the third generation has been developed that could be classified as a fourth generation of ACI. The principle is to implant a neo-cartilaginous tissue. NeoCart utilizes a tissue-engineered implant which combines bovine type-I collagen matrix scaffold with autogenous chondrocytes and bioreactor treatment. The implant can be fixed during the second stage by using fibrin glue rather than suturing, which simplifies the procedure and allows minimal exposure [Crawford]. Novocart 3D is another third generation ACI technology that has been proposed [Zak]. These techniques are still under evaluation and only short term follow up with good result has been reported.

Other techniques and potential directions

Several new and advanced techniques have been proposed and are still in evaluation. The future will probably see the emergence of new techniques and new concepts in order to improve the efficiency, particularly to create a durable hyaline cartilage and to simplify the procedure (one-step versus two-steps).

Minced cartilage

The concept is to use chondral fragments either with a scaffold or in combination with fibrin glue as a carrier in a

one stage cartilage repair procedure [Bonasia]. The minced cartilage can be autogenic or allogenic [Seow]. Two main techniques have been used so far: the Cartilage Autograft Implantation System (CAIS) and the Particulated Juvenile Allograft Cartilage (PJAC).

Cartilage Autograft Implantation System (CAIS)

Autologous hyaline cartilage is harvested arthroscopically (e.g., lateral wall of the intercondylar notch or trochlear ridge). This cartilage is mechanically minced into 1- to 2-mm pieces and then affixed on a synthetic, biodegradable

scaffold (copolymer foam of 35% polycaprolactone and 65% Polyglycolic acid) using fibrin glue. The lesion site is prepared in a manner similar to ACI. The scaffold, loaded with the freshly harvested autologous cartilage chips, is then placed in the lesion site with the minced cartilage facing the bone base. Fixation can be achieved with bioabsorbable staples [Cole].

Particulated Juvenile Articular Cartilage Allograft

Particulated Juvenile Articular Cartilage Allograft (PJCAT) is a one-stage cell based procedure that has been proposed recently (De Novo NT Natural Tissue Graft). The allograft tissue consists of small articular chondral fragments harvested from donors aged less than 13 years. The technique is quite similar to the ACI but it is performed in one-stage: preparation of the defect with stable vertical margins, removal of the calcified cartilage layer, the PJCAT is placed in one layer into the lesion (1 vial per 2.5 cm2), usually secured with fibrin glue and collagen membrane encloses the allograft (Figure 10).

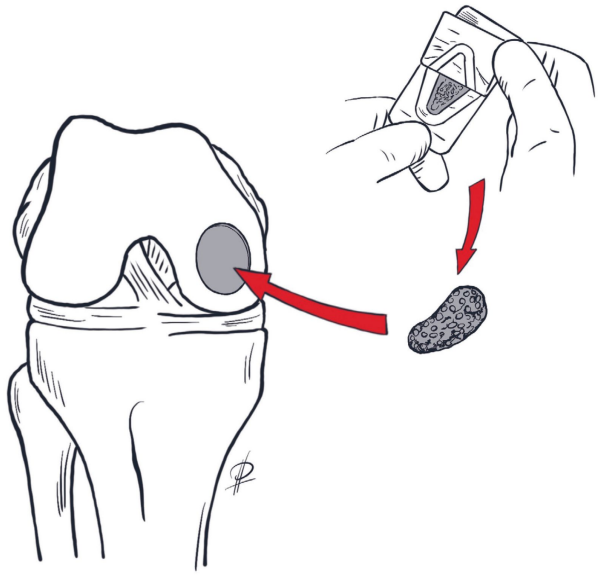


Figure 10: Particulated Juvenile Articular Cartilage Allograft.

It is a relatively simple technique, capable of treating large cartilage lesions in a single stage surgery without any donor site morbidity. There is no violation of the subchondral plate with this technique. The disadvantage is the cost, the availability of the allograft and the limited experience [Ruta, Farr].

The literature has shown good basic science evidence to support the concept of minced cartilage. Although the preliminary clinical reports show encouraging results, clinical data are still limited, especially for CAIS. The indications for both techniques need to be precisely defined (age of the patients, size of the lesion, and involvement of the subchondral bone) [Bonasia].

Another technique has been proposed with the use of extracellular matrix cartilage allografts (BioCartilage). It contains dehydrated, micronized allogeneic cartilage and it is implanted with the addition of PRP (Platel Rich Plasma) over a microfractured defect [Hirahara]. To date and in our knowledge, no clinical studies of extracellular matrix cartilage allograft have been published for knee osteochondral defects.

Stem cells and growth factors

The use of mesenchymal stem cells as a biological approach to treat cartilage lesions has widely increased these last years and there is a growing number of clinical trials in this field [Filardo]. Among the different available stem cells, the most exploited cell types are those derived from bone marrow and adipose tissue. They can be used either after culture expansion or simply concentrated during a one-step procedure [Gobbi 2015]. However, while promising results have been shown as well as no major adverse events have been reported, there is still limited evidence about the use of MSCs for the treatment of articular cartilage. The potential of these treatments should be confirmed by reliable clinical data particularly to define the best cell sources, the safest and more efficient manipulation and the recommended delivery procedures [Filardo].

Growth factors and fibroblast growth factor 2 are active molecules that can stimulate cell growth and therefore enhance chondrogenesis. Platelet-rich plasma (PRP) injections, which contain many of these growth factors are a possible solution to promote chondrogenesis and improve clinical function. Currently, there is low evidence concerning the effect of PRP in cartilage injury. However, some studies have shown an effect on pain and function in early stage of osteoarthritis [Nourissat].

COMPARATIVE STUDIES

Several studies have compared the different techniques of repair and restoration (Richter).

Microfracture versus Osteochondral Autograft Transfer

Both techniques provide good clinical outcomes at intermediate-term follow-up (up to 5 years) after trochlea or condyle cartilage defects.

However, patients treated with mosaicplasty maintained a superior level of athletic activity compared with those treated with microfracture and the clinical outcomes of microfracture seems to be worse in lesions larger than 2 cm2 [Krych 2012]. Gudas et al. has shown a significant superiority of OAT over MF for the repair of articular cartilage defects in the knee and they found that only 52% of MF athletes could return to sports at the preinjury level in comparison to 93% for OAT [Gudas]. Ulstein et al., at long-term follow-up (9.8 years), determine there were no significant differences between patients treated with MF and patients treated with OAT mosaicplasty in patient-reported outcomes, muscle strength or radiological outcome [Ulstein].

Microfracture versus Autologous Chondrocyte Implantation

For Knutsen et al., both methods provided satisfactory results in 77% of the patients at five years [Knutsen 2007]. There was no significant difference in the clinical and radiographic results between the two treatment groups and no correlation between the histological findings and the clinical outcome. One-third of the patients had early radiographic signs of osteoarthritis five years after the surgery. In a study performed by Kon et al., the two techniques seem to have similar success in returning to competitive sport, microfracture allowing a faster recovery but presenting a clinical deterioration over time, whereas arthroscopic second-generation autologous chondrocyte implantation delays the return of high-level male soccer players to competition but can offer more durableclinical results [Kon 2011]. At mid-term (5 years), patients undergoing MF or first/third-generation ACI for articular cartilage lesions in the knee can be expected to experience improvement in clinical outcomes at midterm to long-term follow-up without any significant difference between the groups [Kraeutler].

Knutsen at al, in a more recent study, reported long-term outcomes (14 to 15 years) and they found no significant differences between the treatment groups with respect to the results on the clinical scoring systems. At the 15-

year evaluation, there were 17 failures in the ACI group compared with 13 in the microfracture group [Knutsen 2016]. The quality of the chondrocyte culture must probably be considered as Saris et al. showed than characterized chondrocyte implantation (CCI: manufacturing method developed to optimally preserve the articular cartilage phenotype, resulting in a phenotypically stable cell population) for the treatment of articular cartilage defects of the femoral condyles of the knee results in significantly better clinical outcome at 36 months in a randomized trial compared with MF [Vanlauwe].

Therefore, the results look quite similar at short-term time but they seem to deteriorate with microfracture at long-term follow-up, in comparison to ACI. However, this is still controversial in the literature and needs to be confirmed in further future studies.

Osteochondral Autograft

Transfer Versus Autologous Chondrocyte Implantation

At short-term follow-up, the clinical outcomes are equivalent even if, histologically, the osteochondral cylinder transplants seems to better retain their hyaline character [Horas]. However, for larger defects, the ACI has superior results up to ten years [Bentley] and the mosaicplasty has shown its poor performance for the relatively large articular cartilage defects for which the technique might not be suitable.

Microfracture Versus

Osteochondral Autograft

Transfer Versus Autologous Chondrocyte Implantation

The three types of cartilage repair have been compared. For Lim at al., all three procedures showed improvement in functional scores.

There were no differences in functional scores and postoperative MRI grades among the groups. Arthroscopy at 1 year showed excellent or good results in 80% after MF, 82% after OAT, and 80% after ACI. Their study did not show a clear benefit of either ACI or OAT over MF [Lim].

Mundi et al, had the same conclusion that although MS, ACI, and OAT are all generally efficacious in improving symptoms in patients with focal knee cartilage defects, current best evidence does not support any one surgical technique as a superior method for improving intermediate-term function and pain [Mundi].

In their systematic review, Harris et al. stated that cartilage repair and restoration with microfracture, autologous chondrocyte implantation, and osteochondral autograft has proven short-term and intermediate-term success [Harris]. In their study, the intermediate-term clinical outcomes after autologous chondrocyte implantation demonstrated a trend toward autologous chondrocyte implantation having improved outcomes as compared with microfracture but did not allow them to conclude that there is any difference between autologous chondrocyte implantation and osteochondral autograft transplant.

Based on the evidence from a systematic review performed by Devitt et al., no single treatment can be recommended for the treatment of knee cartilage defects [Devitt].

RETURN TO SPORT AFTER SURGICAL MANAGEMENT OF CARTILAGE DEFECTS

The sport activity can be seriously affected and the career of the athlete can be compromised. Therefore, the treatment of cartilage lesions in the athletic population is clearly challenging. A recent meta-analysis of 2549 athletes showed that the cartilage restoration surgery had a 76 % return to sport at mid-term follow-up [Krych 2017]. Osteochondral autograft transfer offered a faster recovery and appeared to have a higher rate of return to preinjury athletics, but heterogeneity in lesion size, athlete age, and concomitant surgical procedures are important factors to consider when assessing individual athletes. This study provides great information about the results of different surgical cartilage repair procedures but each individual must be considered for the treatment decision.

Campbell et al., in their systematic review, concluded that the athletes may return to sports participation after microfracture, ACI, osteochondral autograft, or osteochondral allograft, but microfracture patients were least likely to return to sports. The athletes who had a better prognosis after surgery were younger, had a shorter preoperative duration of symptoms, underwent no previous surgical interventions, participated in a more rigorous rehabilitation protocol, and had smaller cartilage defects [Campbell].

CONCLUSION / TAKE-HOME MESSAGE

The ideal surgical procedure (The “Holy Grail”) for the treatment of chondral and osteochondral lesions has yet to be defined in 2018. To date, none of the current techniques are able to reproduce a full normal hyaline cartilage in place of the cartilage defect. Many cartilage repair and restoration options are available, with advantages and disadvantages for each surgical technique. The current and available studies are not capable to show strong evidence that one technique is clearly better than the other. There are some tendancies in favour to one or another technique, at short, intermediate and long-term follow-up. The decision-making should rely on multiple factors including age, activity especially sport, type and size of the lesion, cost and geographic/legal availability.

Based on the current evidence, we propose an algorithm for the decision (Figure 11). It is only a guide, based on the current knowledge and it can be adapted and customised according to the patient case and the availability of the technique in the surgeon’s country. The concomitant pathologies (malalignment, ligament laxity or meniscus deficiency) must be identified and addressed to create an optimal environment for cartilage restoration.

ICRS Grade 3 an 4	
Size (cm2)	**Procedure**
< 2	Microfracture (+/- augmentation) Mosaicplasty (high demand)
2 - 4	Mosaicplasty (bone loss) ACI
> 4	ACI Osteochondral allograft (bone loss)

Figure 11: Proposal of treatment algorithm for knee articular cartilage defects.

This algorithm will probably evolve in the future as we can hope that emerging technologies will improve the treatment of cartilage defects in the next decade.

REFERENCES

Benthien JP, Behrens P. Autologous Matrix-Induced Chondrogenesis (AMIC): Combining Microfracturing and a Collagen I/III Matrix for Articular Cartilage Resurfacing. Cartilage. 2010;1(1):65-8.

Bentley G, Biant LC, Vijayan S, Macmull S, Skinner JA, Carrington RW. Minimum ten-year results of a prospective randomised study of autologous chondrocyte implantation versus mosaicplasty for symptomatic articular cartilage lesions of the knee. J Bone Joint Surg Br. 2012 Apr;94(4):504-9.

Bonasia DE, Marmotti A, Rosso F, Collo G, Rossi R. Use of chondral fragments for one stage cartilage repair: A systematic review. World J Orthop. 2015 Dec 18;6(11):1006-11.

Brittberg M, Lindahl A, Nilsson A, Ohlsson C, Isaksson O, Peterson L. Treatment of deep cartilage defects in the knee with autologous chondrocyte transplantation. N Engl J Med. 1994 Oct 6;331(14):889-95.

Bugelli G, Ascione F, Dell'Osso G, Zampa V, Giannotti S. Biphasic bioresorbable scaffold (TruFit(®)) in knee osteochondral defects: 3-T MRI evaluation of osteointegration in patients with a 5-year minimum follow-up. Musculoskelet Surg. 2017 Nov 21. doi: 10.1007/s12306-017-0522-8.

Campbell AB, Pineda M, Harris JD, Flanigan DC. Return to Sport After Articular Cartilage Repair in Athletes' Knees: A Systematic Review. Arthroscopy. 2016 Apr;32(4):651-68

Cole BJ, Farr J, Winalski CS, Hosea T, Richmond J, Mandelbaum B, De Deyne PG. Outcomes after a single-stage procedure for cell-based cartilage repair: a prospective clinical safety trial with 2-year follow-up. Am J Sports Med. 2011 Jun;39(6):1170-9.

Crawford DC, DeBerardino TM, Williams RJ 3rd. NeoCart, an autologous cartilage tissue implant, compared with microfracture for treatment of distal femoral cartilage lesions: an FDA phase-II prospective, randomized clinical trial after two years. J Bone Joint Surg Am. 2012 Jun 6;94(11):979-89.

Devitt BM, Bell SW, Webster KE, Feller JA, Whitehead TS. Surgical treatments of cartilage defects of the knee: Systematic review of randomised controlled trials. Knee. 2017 Jun;24(3):508-517.

Enea D, Cecconi S, Calcagno S, et al. Single-stage cartilage repair in the knee with microfracture covered with a resorbable polymer-based matrix and autologous bone marrow concentrate. Knee 2013;20:562–9.

Familiari F, Cinque ME, Chahla J, Godin JA, Olesen ML, Moatshe G, LaPrade RF. Clinical Outcomes and Failure Rates of Osteochondral Allograft Transplantation in the Knee: A Systematic Review. Am J Sports Med. 2017 Oct 1:363546517732531.

Farr J, Tabet SK, Margerrison E, et al. Clinical, radiographic, and histological outcomes after cartilage repair with particulated juvenile articular cartilage: a 2-year prospective study. Am J Sports Med 2014;42:1417–25.

Ficat RP, Ficat C, Gedeon P, Toussaint JB. Spongialization: a new treatment for diseased patellae. Clin Orthop Relat Res. 1979 Oct;(144):74-83.

Filardo G, Perdisa F, Roffi A, Marcacci M, Kon E. Stem cells in articular cartilage regeneration. J Orthop Surg Res. 2016 Apr 12;11:42.

Gao L, Orth P, Cucchiarini M, Madry H. Autologous Matrix-Induced Chondrogenesis: A Systematic Review of the Clinical Evidence. Am J Sports Med. 2017 Nov 1:363546517740575.

Gelber PE, Batista J, Millan-Billi A, Patthauer L, Vera S, Gomez-Masdeu M, Monllau JC. Magnetic resonance evaluation of TruFit® plugs for the treatment of osteochondral lesions of the knee shows the poor characteristics of the repair tissue. Knee. 2014 Aug;21(4):827-32.

Geraghty S, Kuang JQ, Yoo D, LeRoux-Williams M, Vangsness CT Jr, Danilkovitch A. A novel, cryopreserved, viable osteochondral allograft designed to augment marrow stimulation for articular cartilage repair.

J Orthop Surg Res. 2015;14;10:66.

Gobbi A, Chaurasia S, Karnatzikos G, et al. Matrix-induced autologous chondrocyte implantation versus multipotent stem cells for the treatment of large patellofemoral chondral lesions: a nonrandomized prospective trial. Cartilage 2015;6:82–97.

Gomoll A, Probst C, Farr J, et al. Use of a type I/III bilayer collagen membrane decreases reoperation rates for symptomatic hypertrophy after autologous chondrocyte implantation. Am J Sports Med 2009;37:20S–3S.

Goyal D, Keyhani S, Lee EH, Hui JH. Evidence-based status of microfracture technique: a systematic review of level I and II studies. Arthroscopy. 2013 Sep;29(9):1579-88.

Gudas R, Kalesinskas RJ, Kimtys V, et al. A prospective randomized clinical study of mosaic osteochondral autologous transplant versus microfracture for the treatment of osteochondral defects in the knee joint in young athletes. Arthroscopy. 2005;21:1066-1075.

Hangody L, Fules P. Autologous osteochondral mosaicplasty for the treatment of full-thickness defects of the weight-bearing joints: ten years of experimental and clinic experience. J Bone Joint Surg Am. 2003;85-A(suppl 2):25-32.

Hangody L, Vásárhelyi G, Hangody LR, et al. Autologous osteochondral grafting—Technique and long-term results. Injury 2008;39:32–9.

Harris JD, Siston RA, Pan X, Flanigan DC. Autologous chondrocyte implantation: a systematic review. J Bone Joint Surg Am. 2010;92:2220-2033.

Hirahara AM, Mueller KW Jr. BioCartilage: A New Biomaterial to Treat Chondral Lesions. Sports Med Arthrosc. 2015 Sep;23(3):143-8.

Horas U, Pelinkovic D, Herr G, Aigner T, Schnettler R. Autologous chondrocyte implantation and osteochondral cylinder transplantation in cartilage repair of the knee joint: a prospective, comparative trial. J Bone Joint Surg Am. 2003;85-A:185-192.

Hunter W. On the structure and disease of articulating cartilage. Philos Trans R Soc Lond 1734;42:514–21.

Johnson LL. Arthroscopic abrasion arthroplasty historical and pathologic perspective: present status. Arthroscopy. 1986;2(1):54-69.

Knutsen G, Drogset JO, Engebretsen L, et al. A randomized trial comparing autologous chondrocyte implantation with microfracture: findings at five years. J Bone Joint Surg Am. 2007;89:2105-2112

Knutsen G, Drogset JO, Engebretsen L, Grøntvedt T, Ludvigsen TC, Løken S, Solheim E, Strand T, Johansen O.

A Randomized Multicenter Trial Comparing Autologous Chondrocyte Implantation with Microfracture: Long-Term Follow-up at 14 to 15 Years. J Bone Joint Surg Am. 2016 Aug 17;98(16):1332-9.

Kon E, Filardo G, Berruto M, et al. Articular cartilage treatment in high-level male soccer players: a prospective comparative study of arthroscopic second generation autologous chondrocyte implantation versus microfracture. Am J Sports Med. 2011;39:2549-2557.

Kon E, Filardo G, Di Martino A, et al. Clinical results and MRI evolution of a nano-composite multilayered biomaterial for osteochondral regeneration at 5 years. Am J Sports Med 2014;42:158–65.

Kraeutler MJ, Belk JW, Purcell JM, McCarty EC. Microfracture Versus Autologous Chondrocyte Implantation for Articular Cartilage Lesions in the Knee: A Systematic Review of 5-Year Outcomes. Am J Sports Med. 2017 Apr 1:363546517701912.

Krych AJ, Gobbi A, Lattermann C, Nakamura N. Articular cartilage solutions for the knee: present challenges and future direction. JISAKOS 2016;1:93–104.

Krych AJ, Harnly HW, Rodeo SA, Williams RJ 3rd. Activity levels are higher after osteochondral autograft transfer mosaicplasty than after microfracture for articular cartilage defects of the knee: a retrospective comparative study. J Bone Joint Surg Am. 2012;94:971-978.

Krych AJ, Pareek A, King AH, Johnson NR, Stuart MJ, Williams RJ 3rd. Return to sport after the surgical management of articular cartilage lesions in the knee: a meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2017 Oct;25(10):3186-3196.

Lee YH, Suzer F, Thermann H. Autologous Matrix-Induced Chondrogenesis in the Knee: A Review. Cartilage. 2014;5(3):145-53.

Levy YD, Görtz S, Pulido PA, McCauley JC, Bugbee WD. Do fresh osteochondral allografts successfully treat femoral condyle lesions? Clin Orthop Relat Res. 2013 Jan;471(1):231-7.

Lim HC, Bae JH, Song SH, Park YE, Kim SJ. Current treatments of isolated articular cartilage lesions of the knee achieve similar outcomes. Clin Orthop Relat Res. 2012;470:2261-2267.

Minas T, Von Keudell A, Bryant T and, et al. The John Insall Award: a minimum 10-year outcome study of autologous chondrocyte implantation. Clin Orthop Relat Res 2014;472:41–51.

Mundi R, Bedi A, Chow L, Crouch S, Simunovic N, Sibilsky Enselman E, Ayeni OR. Cartilage Restoration of the Knee: A Systematic Review and Meta-analysis of Level 1 Studies. Am J Sports Med. 2016 Jul;44(7):1888-95.

Nourissat G, Mainard D, Kelberine F; French Arthroscopic Society (SFA). Current concept for the use of PRP in arthroscopic surgery. Orthop Traumatol Surg Res. 2013 Dec;99(8 Suppl):S407-10.

Peterson L, Vasiliadis HS, Brittberg M and, et al. Autologous chondrocyte implantation: a long-term follow-up. Am J Sports Med 2010;38:1117–24.

Pridie KH. The method of resurfacing osteoarthritic knee joints. J Bone Joint Surg Br 1959;41:618–23.

Richter DL, Schenck RC Jr, Wascher DC, Treme G. Knee Articular Cartilage Repair and Restoration Techniques: A Review of the Literature. Sports Health. 2016;8(2):153-60.

Ruta DJ, Villarreal AD, Richardson DR. Orthopedic Surgical Options for Joint Cartilage Repair and Restoration. Phys Med Rehabil Clin N Am. 2016;27(4):1019-1042.

Seow D, Yasui Y, Hurley ET, Ross AW, Murawski CD, Shimozono Y, Kennedy JG. Extracellular Matrix Cartilage Allograft and Particulate Cartilage Allograft for Osteochondral Lesions of the Knee and Ankle Joints: A Systematic Review. Am J Sports Med. 2017 Aug 1:363546517717494.

Steadman JRMD, Rodkey WGDVM and Rodrigo JJMD. Microfracture: surgical technique and rehabilitation to treat chondral defects. Clin Orthop Relat Res 2001;391:S362–9.

Steinwachs MR, Waibl B, Mumme M. Arthroscopic treatment of cartilage lesions with microfracture and BSTCarGel. Arthrosc Tech 2014;3:e399-e402.

Stanish WD, McCormack R, Forriol F, et al. Novel scaffold-based BST-CarGel treatment results in superior cartilage repair compared with microfracture in a randomized controlled trial. J Bone Joint Surg Am 2013;95:1640–50.

Siclari A, Mascaro G, Gentili C, et al. Cartilage repair in the knee with subchondral drilling augmented with a platelet-rich plasma-immersed polymer-based implant. Knee Surg Sports Traumatol Arthrosc 2014;22:1225–34.

Solheim E1, Hegna J, Øyen J, Harlem T, Strand T. Results at 10 to 14 years after osteochondral autografting (mosaicplasty) in articular cartilage defects in the knee. Knee. 2013;20:287-290.

Stanish WD, McCormack R, Forriol F, et al. Novel scaffold-based BST-CarGel treatment results in superior cartilage repair compared with microfracture in a randomized controlled trial. J Bone Joint Surg Am 2013;95:1640–50.

Steadman J, Rodkey W and Briggs K. Microfracture to treat full-thickness chondral defects: surgical technique, rehabilitation, and outcomes. J Knee Surg 2002;15:170–6.

Ulstein S, Årøen A, Røtterud JH, Løken S, Engebretsen L, Heir S. Microfracture technique versus osteochondral autologous transplantation mosaicplasty in patients with articular chondral lesions of the knee: a prospective randomized trial with long-term follow-up. Knee Surg Sports Traumatol Arthrosc. 2014;22:1207-1215.

Vanlauwe J, Saris DB, Victor J, Almqvist KF, Bellemans J, Luyten FP; TIG/ACT/01/2000&EXT Study Group. Five-year outcome of characterized chondrocyte implantation versus microfracture for symptomatic cartilage defects of the knee: early treatment matters. Am J Sports Med. 2011 Dec;39(12):2566-74.

Versier G, Dubrana F; French Arthroscopy Society. Treatment of knee cartilage defect in 2010. Orthop Traumatol Surg Res. 2011;97(8 Suppl):S140-53.

Widuchowski W, Widuchowski J, Trzaska T (2007) Articular cartilage defects: study of 25,124 knee arthroscopies. Knee;14(3):177–182

Zak L, Albrecht C, Wondrasch B, Widhalm H, Vekszler G, Trattnig S, Marlovits S, Aldrian S. Results 2 Years After Matrix-Associated Autologous Chondrocyte Transplantation Using the Novocart 3D Scaffold: An Analysis of Clinical and Radiological Data. Am J Sports Med. 2014 Jul;42(7):1618-27.