



KNEE ARTICULAR CARTILAGE REPAIR AND ATHLETES

This article presents an overview of the latest articular cartilage surgical techniques and cartilage repair rehabilitation principles and their practical implementation. A return to pre-injury performance levels is not guaranteed, and for some athletes articular cartilage injuries may be career-ending. In such cases, the role of the healthcare professional switches to considering how to keep the athlete exercising when they retire from competition.

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INTRODUCTION

Articular cartilage injuries are not a new problem. As far back as the mid-eighteenth century it was identified that damaged articular cartilage does not heal once injured. Over the past 50 years scientists and surgeons have been increasingly challenged to develop a biological alternative to the traditional knee replacement that can offer a more cost-effective, durable and acceptable alternative for the millions of people with osteoarthritis worldwide. With over two million articular cartilage defects being diagnosed each year in Europe and the USA, interest in cartilage repair has escalated. This article sets out to give up-to-date information regarding cartilage repair surgery and rehabilitation and discusses why cartilage repair remains so troublesome to the athletic population.

HOW DO CHONDRAL INJURIES OCCUR?

Articular cartilage damage can result from:

- Acute trauma (blunt or shear)
- Chronic repetitive trauma (excessive

focal mechanical overload)

- Osteochondritis dissecans.

Focal grade IV chondral defects can occur within a year of acute knee trauma or surgery (usually ACL or meniscal) (1). Articular cartilage damage should be considered if an athlete experiences pain at rest, has had recent ligament or meniscal injury, and/or has chronic knee pain and other diagnoses have been excluded and/or conservative treatment has failed.

RELEVANCE TO ATHLETES

Articular cartilage defects are one of the most common causes of permanent disability in athletes (2). Excessive stress on a joint with an articular cartilage defect may accelerate further degenerative changes and predispose the athlete to a higher risk of osteoarthritis. One important study showed that, although 75% of young athletes with severe chondral damage returned to pre-injury sport levels, 14 years later 43% showed radiographic joint space narrowing (3). Athletes require an articulating cartilage surface that can withstand the high mechanical joint stresses generated

during their specific sports activity. Articular cartilage is avascular and does not have the natural healing ability of other tissues, and this often leads to the need for surgical intervention. Management of an athlete with articular cartilage damage is consequently a significant challenge to healthcare professionals (Fig. 1).

CARTILAGE REPAIR

At present we are unable to regenerate hyaline articular cartilage, but the articulating surface can be repaired with a functional tissue. In order to implement optimal rehabilitation for an athlete, it is important to be familiar with articular cartilage repair techniques. The three current categories of cartilage repair techniques are described below.

Marrow-stimulating: microfracture

The microfracture technique, as pioneered by Dr Richard Steadman, involves removing the damaged cartilage to expose the underlying bone. The subchondral bone is then penetrated with an awl to expose the

blood vessels. This generates a blood clot, which facilitates the migration of bone marrow cells into the defect. Microfracture is generally performed as an arthroscopic procedure as a first-line treatment in patients with smaller (<2cm²) isolated chondral defects. The blood clot takes about eight weeks to convert to fibrous tissue and therefore needs to be protected. The fact that the repair tissue generated by microfracture is often fibrocartilage, which is not as durable as hyaline cartilage, has led some clinicians to question its role as a first-line treatment for high-demand athletes.

Osteochondral grafts: OATS/mosaicplasty

Osteochondral grafting involves taking full-thickness cylindrical plugs of articular cartilage attached to subchondral bone from a non-weight-bearing area of the knee. These plugs are then inserted into matching holes that have been drilled in the chondral defect. This is completed during a single operation either arthroscopically or via a small arthrotomy. The plugs are comprised of hyaline cartilage, but the spaces around the plugs fill in with fibrocartilage, as does the donor site. The biggest problem with this technique is donor site morbidity, and consequently it is often limited to chondral defects less than 4cm² in size. The benefit of this technique is that the grafts are mature subchondral plugs, so although it is not quite 'plug and return to sport', timescales are generally quicker than with other cartilage repair techniques.

Cell-based repair

A new cell-based therapy for the treatment of cartilage defects called autologous chondrocyte implantation (ACI) was developed in the 1980s, and the results of the first human trial were published in 1994 (4). Currently ACI is the most widely researched cartilage repair technique. ACI is generally a two-stage procedure (5), although several European countries have started to perform the technique in a single arthroscopic procedure. The first stage involves an arthroscopic assessment of the chondral defect. A small sample of cartilage is harvested from a non-weight-bearing area of the femur. This sample is cultured for 3–6 weeks until there are sufficient chondrocytes to fill

the defect (many millions). The second stage involves trimming back the chondral defect so that all the edges are healthy cartilage and the underlying bone is exposed. The cultured cells are then reintroduced back into the defect and kept in place by a periosteal or collagen membrane; alternatively, the cells are seeded directly on to a membrane or matrix that is then secured in the defect. This is a fast-moving area in medicine, and new variations of the ACI technique emerge frequently.

For a comprehensive outline of indications, contraindications, techniques and outcomes of the various cartilage repair surgical options, readers are directed to the reference list (6–20).

REHABILITATION FOLLOWING CARTILAGE REPAIR

Cartilage adaptation is slow compared with that of other soft tissues (Fig. 2). Over a period of 2 years, only 75% adaptation of cartilage tissue can be expected. This is highly relevant for the rehabilitation of chondral injuries and post-cartilage repair procedures. On the one hand, Wolff's law dictates that 'form follows function' and physical demands need to be placed on the tissue for remodelling to occur. On the other hand, chondral tissue is slow to adapt to increasing loads and is often the weakest link in the tissue chain, so an element of protection against potentially damaging loads is necessary. There is therefore a delicate balance between exposing the repair tissue to sufficient loading in order to stimulate chondral matrix production and minimising the exposure to levels of loading that could lead to mechanical failure of the repair (Fig. 3).

The primary rehabilitation goals for an athlete are the local adaptation and remodelling of the repair; a return to full function, including sport and exercise; and the prevention of re-injury and further degeneration in later life. In order to achieve these goals, an optimal environment is required that addresses mechanical, chemical and psychological issues. Although a direct evidence base for cartilage repair rehabilitation is sparse (21), there is an available underpinning scientific framework (22–26). The fundamental principle behind cartilage repair

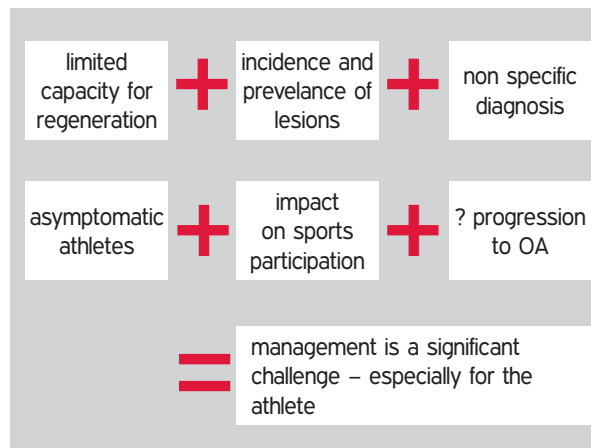


Figure 1: Cartilage is troublesome

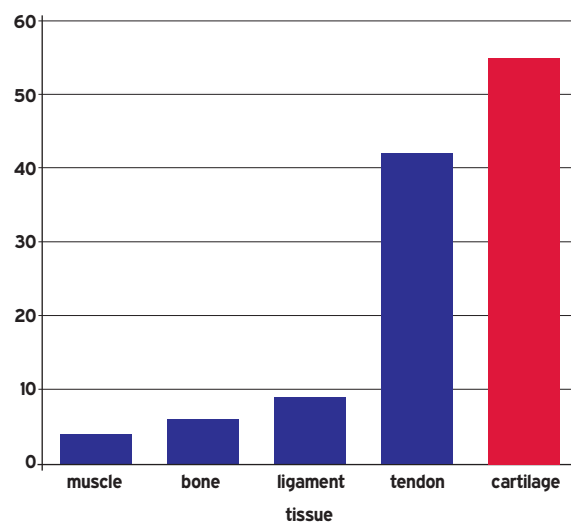


Figure 2: Speed of adaptation of various tissues of the body, as determined by the time to replace half of the cells of each tissue.

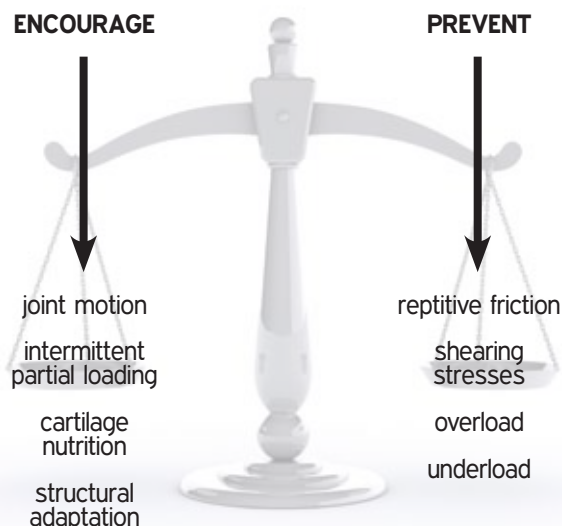


Figure 3: Function versus protection

rehabilitation is that of adapting the rehabilitation to optimise loading, and this requires consideration of:

- Exercise programming
- Stages and timescales of tissue healing
- Clinical biomechanics
- Chondrocyte maturation.

The rehabilitation programme, including progression rates, should be individualised for each athlete based on the following factors, all of which have the potential to influence outcome:

- Lesion size
- Lesion location: tibiofemoral joint or patellofemoral joint
- Concomitant procedures
- Preoperative duration of symptoms
- Preoperative baseline condition
- Age
- Athlete motivation and individual goals.

Rehabilitation should ideally mirror the state of the repair tissue and its ability to accept load. Despite the fact that the three main categories of cartilage repair have different timescales for the acceptance of loading (Fig. 4), any athlete undergoing cartilage repair will progress through the three rehabilitative phases of protection, function and activity. These are not discrete phases, and at any one point therapy may be split between more than one of these phases. There has been great progress over the past few years in the development of magnetic resonance imaging (MRI) protocols for the evaluation of cartilage repair tissue, but this is still work in progress and there are accessibility issues even for elite athletes. From a practical rehabilitative perspective, the status of the repair tissue is usually assessed indirectly through the patient's clinical signs and symptoms during and after therapy sessions. Consequently, adapting the content of the rehabilitation programme to match the status of the repair requires vigilance in monitoring the patient's condition.

Early mobilisation is essential, as stiffness is the 'kiss of death' for the knee. If cartilage is not exposed to sufficient loading within a matter of a few weeks, then the cartilage thickness and stiffness reduce (27). Some of the main adverse events reported after ACI procedures between 1996 and

CARTILAGE REPAIR	REPAIR TISSUE & RETURN TO SPORTS	
microfracture	super clot → fibrocartilage	return to sport 8-10 months
OATS/ mosaicplasty	immediate defect fill with plugs fibrocartilage infill around plugs	return to sport 6-9 months
autologous chondrocyte implantation	0-6wks 7 weeks – 6months 6 months – 3 years	soft primitive gelatinous tissue "wave-like" → putty-like increased tissue stiffness return to sport 12 – 18 months

2003 included adhesions, arthrofibrosis and mechanical complications (28), which could potentially be attributed to the conservative rehabilitation that was adopted during this time. Later research has indicated that it may now be possible to accelerate cartilage repair rehabilitation without any detrimental effects to the repair tissue (26). In order to minimise the risk of scar tissue formation, it is critical to teach the athlete mobilisations for the patella, especially the quadriceps tendon and patellar tendon.

Exercise selection should be focused on achieving specific functional rehabilitation goals (eg. range of movement, strength, endurance, proprioception) while minimising the risk of exposure of the repair site to excessive stress (especially shear, as this creates tensile stress on the repair site). The early postoperative stages of rehabilitation will have a strong focus on protection of the repair site and generally involve restrictions in weight-bearing and range of movement, as determined by the repair location. However, it is important that these restrictions are not seen as barriers to progressing towards the rehabilitation goals. It is possible to select exercises and adapt them so that the athlete can work on a particular rehabilitation goal while adhering to the postoperative guidelines. See practical example 1.

When an athlete is restricted to partial weight-bearing there are a couple of areas that are a good investment of the therapist's time within the preoperative and early postoperative phases of rehabilitation (29). Checking and reinforcing proficiency in judgement of the amount



Figure 4:
Cartilage repair procedures and return to sport

Figure 5: 'Clam' exercise

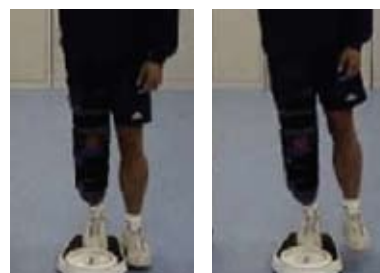


Figure 6: 'Hip Hike' starting position

Figure 7: 'Hip Hike' end position

of weight the athlete is putting through the repaired leg can be implemented using a simple method with two sets of bathroom scales (Fig. 8). Athletes should be advised not to 'toe-touch' weight-bear, as this has the potential

PRACTICAL EXAMPLE 1

The athlete is in the early stages of post-cartilage repair surgery. One of the rehabilitation goals is to retrain and strengthen the gluteus medius.

Patient 1: medial femoral condyle repair and has weight-bearing restrictions.

Solution: use 'clam' exercise (Fig. 5).

Patient 2: patella repair and has range-of-movement restrictions.

Solution: use hip hike with leg in full extension (Figs 6 and 7).



Figure 8: Using scales to assess partial weight-bearing



Figure 9: Demonstration of heel-toe-touch down weight-bearing

to lead to altered gait patterns and shortening of the gastrocnemius and soleus muscles; in preference, they should use 'heel-toe-touch-down' weight-bearing (Fig. 9).

Most athletes want to return to sports-specific skills as soon as possible. A good way to introduce some sports specific-skills earlier in the rehabilitation period is in the pool, using antigravity suits or buoyancy aids to minimise loading on the knee.

RETURN TO SPORT

Returning to sports and exercise activity is one of the main reasons given for individuals electing to undergo cartilage repair surgery (30). Function in sports is viewed as an issue of high importance by patients after cartilage repair (31). Cartilage repair rehabilitation is lengthy, and the neocartilage may take up to three years to mature. The big question is how long is it necessary to hold back the athlete from returning to sport?

For any athlete, return to sport is a risk assessment. First and foremost the athlete has to be ready to accept the load of their sport. If they are not ready to do this, then they should not return to their sport at that stage. Load acceptance is not only the ability of the cartilage repair tissue to accept the load but also the whole person being able to accept the load physically, chemically, biomechanically and psychologically. If the athlete is ready to accept the load of their sport, then the athlete needs to be assessed to determine whether or not the risks of injury/re-injury or future disability outweigh the benefits of returning to the sport. The level of the athlete is

a consideration in this assessment: for the non-elite athlete it may be a case of looking at long-term survival, whereas for the elite athlete it may be the different scenario of a 'quick fix' to enable them to collect a pay cheque for another two or three seasons. Several studies have documented return-to-sport timescales following cartilage repair (see Fig. 4), but these are general guidelines as return-to-sport variables are frequently not assessed or are reported inadequately.

Consider managing the returning athlete differently in their first season back by looking at decreasing sessions, increasing cross-training or playing more half-games.

A return to pre-injury performance levels is not guaranteed, and for some athletes articular cartilage injuries may be career-ending. In this instance, the role of the healthcare professional switches to considering how to keep the athlete exercising when they retire from competition.

Education on the physical expectations for an athlete returning from cartilage repair is important. Communication with the athlete, the coach and the management team is crucial.

Not all athletes who are physically ready and able to return to their sport actually do so. In the study by Mithoefer and colleagues, 83% of competitive players returned to football after ACI surgery. However, of the 26 recreational players in the study, 14 players had excellent or good clinical outcomes and yet none returned to football at any level (6). It should be recognised that cartilage repair rehabilitation is a long process and psychosocial factors have an impact on return-to-sport outcomes, as can be seen from the patients in practical example 2, who were both deemed to have excellent clinical outcomes after undergoing cartilage repair procedures.

WHICH ATHLETES DO BEST?

Overall published success rates from articular cartilage repair range from 60% to 96% for the general population. Initially patellofemoral joint repairs showed considerably lower success rates compared with tibiofemoral joint repairs. Although this trend continues, the gap is closing. On the basis of studies over the past ten years, there

are indications that some athletes have better outcomes than others following cartilage repair. Athletes who have been shown to do better are those who:

- Are younger (<40 years of age)
- Have a shorter pre-operative duration of symptoms (<12 months)
- Have had fewer previous surgeries
- Have smaller defects (<2cm²)
- Have any mechanical malalignment corrected before or at the time of the cartilage repair surgery
- Participate in lower-impact sports
- Are professional or competitive athletes
- Are motivated to return.

When treating an athlete who has undergone cartilage repair, the more information you have to hand the better. Find out exactly what the surgery entailed and whether any concomitant procedures were performed. Where possible get copies of the operative notes, MRI reports and any documentation on the precise defect size and location. It is important for exercise selection to know not only which articulating surface has been repaired but also where the surface was repaired – medial, lateral, proximal or distal. Get a copy of the rehabilitation guidelines given to the athlete. Do not assume that cartilage repair centres always use the same rehabilitation guidelines – they don't!

SUMMARY

Articular cartilage repair has made amazing progress over the past 20 years, but to date the optimal level of mechanical stimulation or the level of pathological overload for repair tissue at different rehabilitation stages has not been determined. The results of cartilage repair studies look increasingly promising, but a universal solution for athletes is not available. No surgical technique is able to regenerate 100% hyaline cartilage, and there is a clinical trade-off associated with all of the current cartilage repair procedures. Any athlete contemplating cartilage repair should be fully informed and aware of the implications before electing to undergo surgery, as a return to pre-injury levels of sports participation is by no means assured.

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PRACTICAL EXAMPLE 2

Athlete 1: 'Even though the doctor told me it was OK to go back to martial arts, I was not about to get back into a sport that puts a lot of pressure on the knee after going to this effort to repair it.'

Athlete 2: 'If I choose to go back to playing sport, then it would be with trepidation. I'm not really prepared to put myself or my family through the long rehab programme again.'

Some athletes who return to sport opt for a lower-impact sport, while others return to their original sport but with limitations in level, frequency and/or duration of training and competition.

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USEFUL WEBSITES AND ASSOCIATIONS

- Cartilage Health: www.cartilagehealth.com
- Cartilage Repair Center, Boston: www.cartilagerepaircenter.org
- Cartilage Research Foundation: www.cartilagefoundation.org
- Chester Knee Clinic & Cartilage Repair Centre: www.kneeclinic.info
- International Cartilage Repair Society: www.cartilage.org
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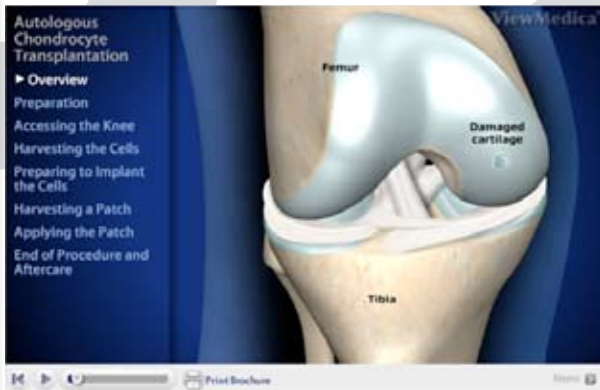


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KNEE ARTICULAR CARTILAGE REPAIR AND ATHLETES

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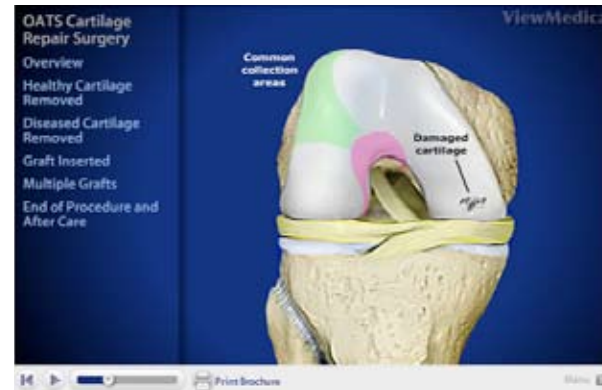
Autologous chondrocyte transplantation - (note: animation only covers first generation procedure)



Cartilage repair - (note: animation only covers first generation procedure)



Microfracture drilling procedure for isolated chondral defect (microfracture drilling)



OATS cartilage repair surgery (OATS)