CARTILAGE RESTORATION SURGERY

WHAT IT TAKES TO MAKE IT A SUCCESS

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INTRODUCTION

Prior to the introduction of technological advancements in joint restoration and cartilage surgery, the operative interventions for patients with large cartilaginous and meniscal defects were limited. However, in recent years, surgical innovations in implants, technique, and biologics have provided surgeons with the tools needed to offer patients more options than were available in prior years. The surgical procedures are highly specialized and require a thorough understanding of the delicate relationship between biology, biomechanics, and surgical techniques of osteotomies, meniscal transplants, and ligament surgery. Our goal in this overview of articular cartilage restoration is to understand these delicate relationships and ultimately treat the patient successfully. A brief description of the various techniques and considerations utilized by successful joint restoration surgeons in managing these pathologies.

HISTORY OF CARTILAGE SURGERY

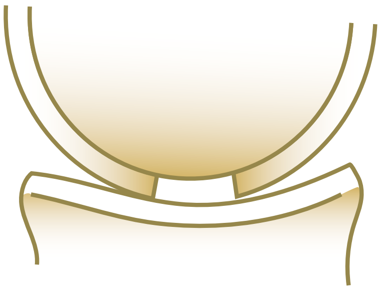
A brief history of joint restoration surgery is important to understand the progression from the first joint restoration procedure to the current state of joint restoration surgery. It's been almost a one hundred years that surgeons have recognized the importance of restoring the articular surface of the knee. The first knee cartilage restoration procedure was recorded by Lexer in 1925, when he reported the first osteoarticular transplant procedure[1]. Since then, further advancements have been made in osteochondral allograft transplantation by Drs. Gross, Meyers, and Convery[2,3,4,5] which was first used in tumor surgery. Bugbee introduced the procedure to sports medicine and has shown excellent clinical results in athletes. Marrow stimulation saw advancements from the classic Pridie method of the 1950s, which was an open method to stimulate regeneration of new collagen. This was then modified for arthroscopic procedures and initially began with "abrasionplasty" by Johnson, and marrow stimulation eventually evolved into the Steadman technique, which involved an arthroscopic debridement of the lesion and subchondral drilling to stimulate type 1 collagen formation[6]. We have now progressed to techniques in cell-based techniques for cartilage restoration. This first began with the work of Dr. Lars Peterson and autologous chondrocyte implantation in rabbit models in 1984[7]. Currently cellular therapy has progressed to third generation techniques.

MECHANISM OF CARTILAGE INJURY

A significant component of joint restoration procedures is a surgeon's thorough understanding of the knee as an organ. The ligaments, meniscus, and structures supporting the cartilage has to be optimum for the success of the surgery. Cartilage itself is a neural and avascular and depends significantly on the supporting structures. The anatomic and functional relationship between cartilage and the underlying subchondral bone is called the osteochondral unit. This basic unit is fundamentally important to understand when determining treatment strategies for joint restoration surgery. Basic science research has demonstrated that there is a very intimate relationship between articular cartilage and the subchondral bone where there is substantial crosstalk and cellular communication between these layers[8]. The cartilage layer is dependent upon oxygen and nutrient delivery from both the synovial fluid and the subchondral bone[9,10].

The articular cartilage provides a layer of protection to the underlying subchondral

1a SMALL LESION < 2CM^2



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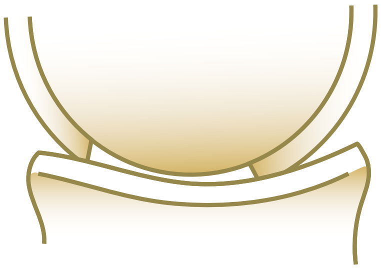

Figure 1: (a and b) Symptoms of small vs large lesion. "Feeling of instability".

Figure 2: Long leg films to determine Mechanical Axis: the line drawn from the center of the femoral head to the center of the ankle. This line should be in approximately in the center of the knee.

bone and provides a low-friction gliding surface, while also distributing joint load over a wide area, and thus minimizing peak pressures upon the subchondral bone[11,12]. What we do know if the osteochondral unit is maintained and there is no significant injury, the cartilage can be functional for a lifetime. Ponzio et al demonstrated that marathon runners, range up to 79 years old had a lower degenerative change in their knee than the general population[40]. Despite receiving nutrients and oxygen from both the synovial fluid as well as the underlying subchondral surface, the articular cartilage unfortunately has very poor healing potential following injury. We also know that the environment or synovial milieu of the knee must be healthy to support the cartilage of the knee, because a constant inflammatory environment will eventually break down the cartilage. The chondral injury can lead to changes in the subchondral bone, and this can play an important role in the development of osteoarthritis. The natural history of these injuries can progress and gradually lead to osteoarthritis, which can cause a tremendous burden on health care systems[41].

Chondral injuries are common and arthroscopic studies have demonstrated up to 60 chondral injuries at the time of arthroscopy and up to 10 percent full thickness lesions. In ACL injuries, up to 60 percent of the chondral lesions may be full thickness. Most of these lesions are asymptomatic and depending on size, location, and depth can become symptomatic over time. Patients who have sustained an articular cartilage injury typically present with pain, swelling, mechanical symptoms, instability, and often report a history of trauma. Any patient with recurrent pain and swelling should have chondral injury on their differential diagnosis. A focused clinical exam on the extremity of interest will often times demonstrates an effusion, pain with active and passive range of motion, and joint line tenderness. The instability that patients feel is not necessarily to an unstable knee but whenever the defect is loaded, there is a feeling of "giving out" or falling into the defect. The larger the defect the more the feeling of instability (Figure 1). Careful inspection of the skin and soft tissue should be completed to evaluate for muscular atrophy and prior incisions. The joint of interest should be evaluated with provocative tests to evaluate the integrity of cruciate and collateral ligaments. A clinical observation with the patient standing and walking can provide valuable information regarding gait antalgia and biomechanical limb malalignment.

Radiographic evaluation typically consists of plain radiographs, standing long leg views for assessment of mechanical alignment, and magnetic resonance imaging. Ideally, an experienced musculoskeletal radiologist is available to assist in evaluating MRI images for ligamentous injuries, meniscal pathology, and lesions of the articular cartilage (Figure 2). In the presence of an articular cartilage injury, there are scoring systems that MSK radiologists use for grading cartilage injuries and repair procedures. The Mocart (Magnetic Resonance Observation of Cartilage Repair Tissue) and AMADEUS (Area Measurement And Depth Underlying Structures) scores are typically calculated to evaluate and grade osteochondral lesions pre- and post-surgery to determine the quality of the chondral repair[13].

TREATMENT

The overall goal of non-operative management in articular cartilage injuries is to improve pain, improve function, and to delay surgery for as long as possible[14]. In the non-operative management of these conditions, AAOS guidelines have provided strong recommendations for physical therapy and NSAID usage and only moderate recommendations for utilization of brace and BMI control; additionally, diagnostic arthroscopy is not recommended.

Surgical options can be discussed once non-operative management options have been exhausted or if the patient has been experiencing unacceptable pain and dysfunction. Once surgical candidacy has been determined, a surgeon must consider the contributing variables to the patient's pathology such as ligamentous insufficiency, meniscal pathology, and structural malalignment. These comorbid conditions can change the knee joint biomechanics by overload of a compartment, instability, and finally a direct injury can lead to further breakdown of the knee. These surgeries are complex because the patient may need on occasion several procedures and may even have to be staged. Prior to scheduling the patient for surgery, they must be made aware of the recovery process, demonstrate a willingness to participate in post-operative rehabilitation protocol, and have clear expectations regarding their prognosis.

Once a patient's surgical candidacy has been determined, the primary surgical treatment of choice is dependent on the size, depth, and location of the osteochondral lesion, as well as the patient's overall level of function, activity, and the age of the patient. Another key factor is the patient's expectations, and the surgery should match their expectations or the patient will be disappointed even though the surgeon himself thought the surgery was a success. The integrity of the underlying subchondral bone must be evaluated for presence or absence of subchondral edema, cystic changes, or any evidence of bony bed compromise. Based off of these factors, the primary surgical intervention to address their cartilaginous lesion may be a simple debridement (chondroplasty), a microfracture procedure, an osteochondral autograft or autograft transplantation, or cellular techniques such as matrix associated autologous chondrocyte implantation (MACI). Secondary surgical interventions must address underlying conditions that may have predisposed the patient to a cartilaginous injury such as ligamentous instability, bony malalignment, or meniscal deficiency. These may be addressed with ACL or any instability repair or reconstruction, realigning osteotomies, and meniscal repairs versus transplants, respectively. The successful joint restoration surgeon has to be comfortable with performing all of these procedures since up to 50% of restoration surgery will involve a concomitant procedure to address the underlying comorbidity along with the chondral procedure.

There are several algorithms for cartilage restoration (Figure 3). These are usually based on size, location, depth, and activity level. While there might be slight differences to which procedure is best for the chondral repair, addressing the comorbidities are the same in all algorithms. It is essential to be comfortable with these procedures or the final cartilage restoration procedure will be more likely to fail. Bode et al demonstrated that MACI success dropped in patients without addressing their malalignment from 89% survival to 58% survival[42]. To preserve any osteochondral procedures, it is imperative to scrutinize the native mechanical alignment, evaluate the joint surface, and perform the appropriate osteotomy for the respective deformity[15]. Common osteotomies include high tibial osteotomy for the varus knee, distal femoral osteotomy for the valgus knee, and tibial tubercle osteotomy for patellar instability or patellofemoral pathology[16,17]. These procedures are indicated to provide for more symmetric joint surface loading; however, they are to be avoided in patients with

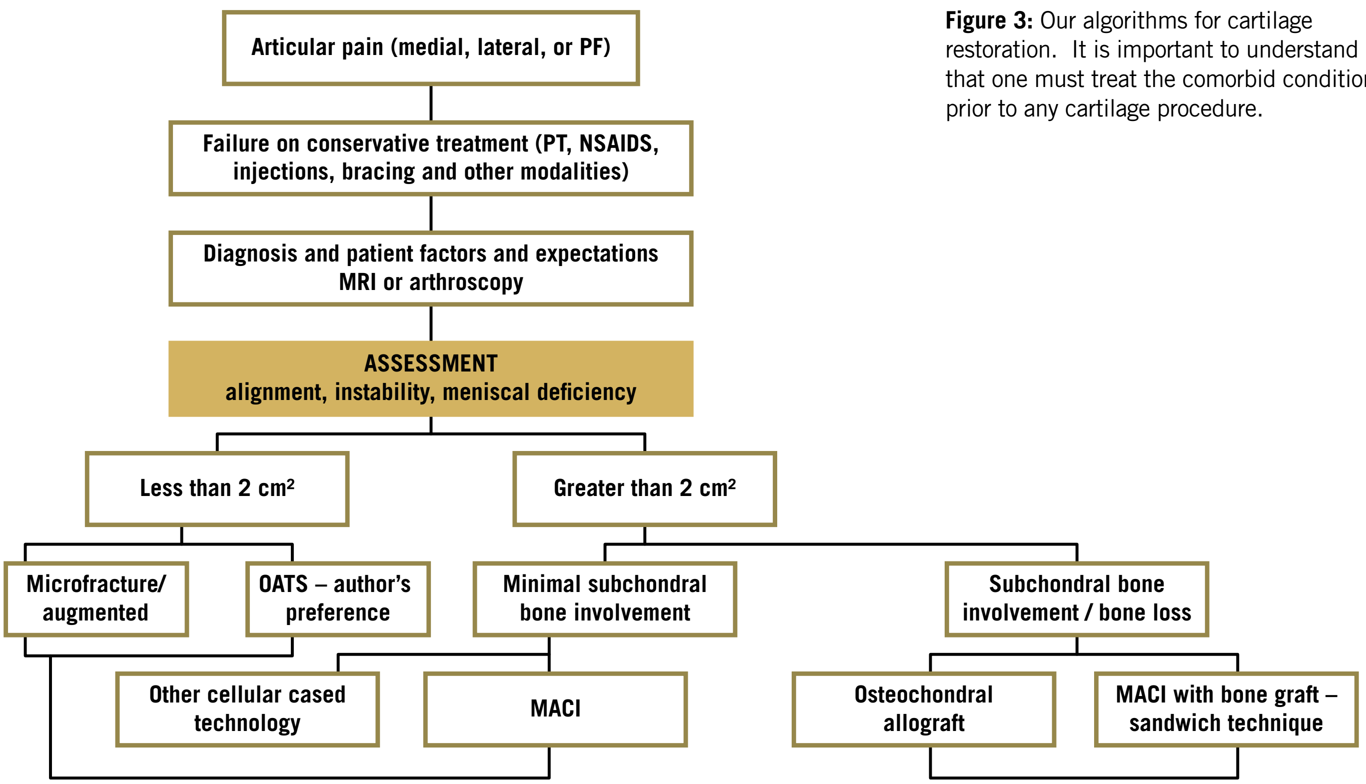

Figure 3: Our algorithms for cartilage restoration. It is important to understand that one must treat the comorbid conditions prior to any cartilage procedure.

inflammatory arthritis and those who are current smokers[18,19].

The high tibial osteotomy can be utilized to correct deformities in both the coronal and sagittal planes and can be completed with a closing wedge or opening wedge osteotomy. While the closing wedge osteotomy was once the most commonly used technique, opening wedge osteotomies have become the more preferred option given their perceived greater safety, relatively less challenging surgical technique, as well as the ability to fine-tune the correction after the osteotomy has been performed[20] (Figure 4). Additionally, medial opening wedge osteotomies offer a low risk of injury to the common peroneal nerve while also avoiding any violation of the posterolateral structures and tibiofibular joints. However, unlike a closing wedge osteotomy, the opening wedge relies on a bone graft to maintain the correction which inevitably increases risk of delayed healing, nonunion, possible loss of correction, and extended weight-bearing restrictions[21]. Lateral closing wedge osteotomies on the other hand, do not rely on bone grafts and are permitted earlier weight-bearing, however if the lateral approach requires a fibular osteotomy, then there is also a risk of peroneal nerve injury and fibular nonunion[22].

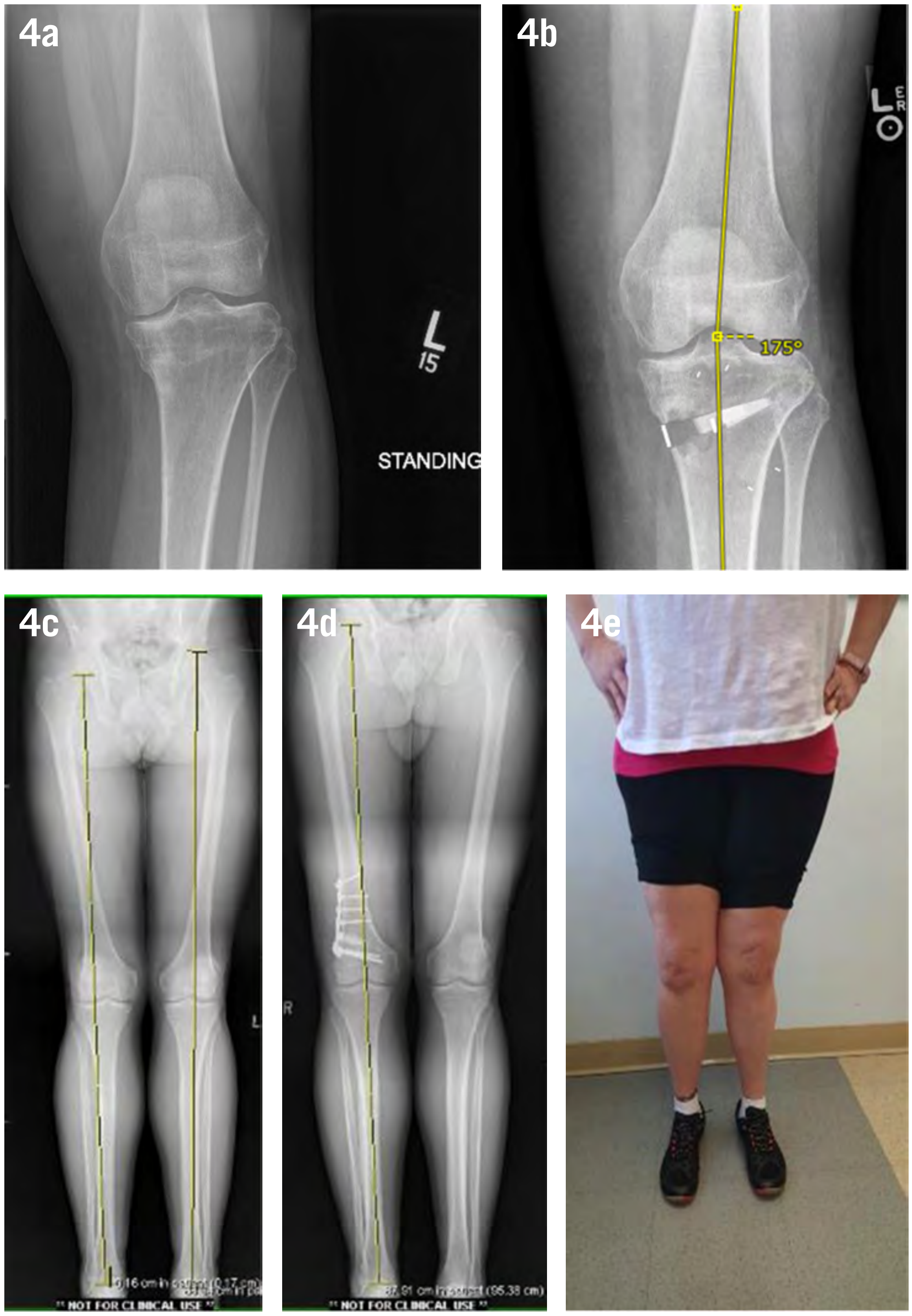

Figure 4: (a and b) High Tibial Osteotomy. (c, d, e) Right knee distal femoral osteotomy.

In patients with genu valgum deformity, the distal femoral osteotomy is another tool utilized by joint restoration surgeons. Medial closing wedge osteotomy and lateral opening wedge osteotomies are two techniques to produce a neutral mechanical alignment[23]. Distal femoral osteotomies are less commonly utilized than HTO's, comprising approximately 5-10% of corrective osteotomies.

In patients with patellofemoral pathology, a tibial tubercle osteotomy may be utilized for the appropriate pathology. An osteotomy of the tibial tubercle can be mobilized and placed in position of stability given the specific etiology. For patients with patellofemoral pathology and patella alta, a TTO may be performed, and the tibial tubercle can be anterior, anteromedial, distal, or proximal[24,25].

As previously mentioned, the goal of corrective osteotomies is to minimize pain, disability, and delay arthroplasty for as long as possible. Several studies have demonstrated reassuring outcomes up to a decade past surgery. Pincewski et al reported 79% survival at 10 years, with 85% of patients satisfied with their result at 12 years[26]. In a meta-analysis performed by Lee et al, investigators found 91% survival at 10 years in patients who had undergone a medial opening wedge high tibial osteotomy[27].

Despite these reassuring outcomes, corrective osteotomies do carry their own risk of complications. Complications that surgeons must be cognizant of include but are not limited to fracture, failure of fixation, and infection. Additionally, there is the risk of over or under correction, delayed union/non-union, and risk of neurovascular injury[19].

Corrective osteotomies are recommended in the appropriate patient population as they can help preserve the quality and the longevity of a concomitant cartilage procedure. In addition to osteotomies, meniscal procedures must also be considered to preserve cartilage restoration surgeries[28]. Patients that require a cartilage procedure must also have a functional meniscus. In patients who have undergone a subtotal or total meniscectomy,

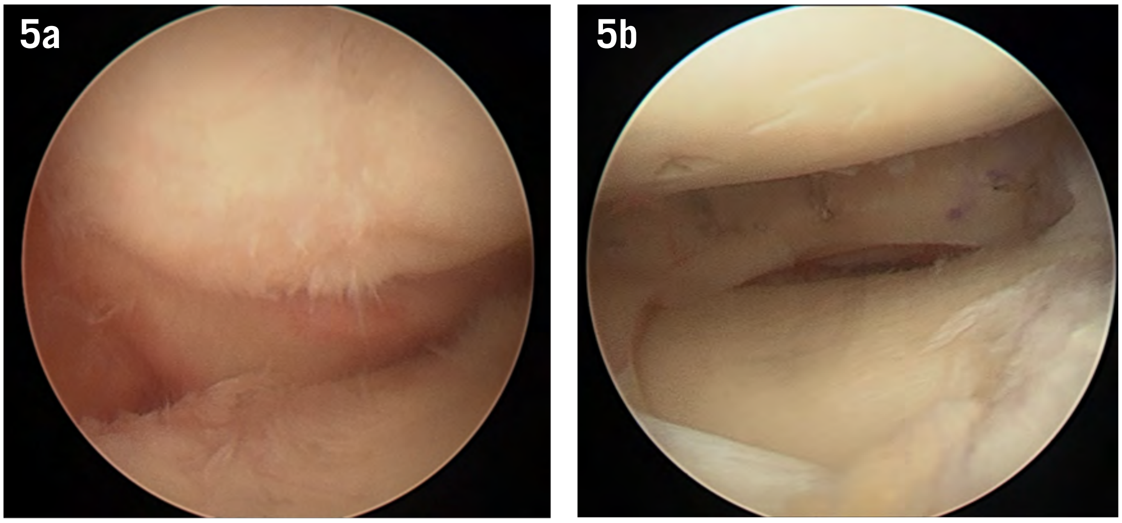

Figure 5: Meniscal transplantation (lateral meniscus).

Figure 6: Microfracture and oats procedures.

a meniscal transplant should be considered prior to any osteochondral procedure[29,30] (Figure 5). Preoperative planning for this type of procedure typically consists of AP and lateral imaging, and using the Pollard technique, radiographic measurements are acquired on AP and lateral views[31]. Non-irradiated fresh frozen or viable meniscal allografts are prepared for transplant and secured to the tibial plateau through slot or bone plug techniques[32]. In a meta-analysis by Verdonk et al, meniscal transplant was deemed a viable option only in young patients and found 80% survival rate at about 5 years[33]. Samitier et al reported a 75% return to sport rate, and a failure rate of about 10-29%[34].

The role of corrective osteotomies and meniscal transplants in cartilage surgery is to provide the optimal environment for the respective osteochondral procedure. Also, any ligamentous instability, such as ACL or multiligament injury, must be addressed at the time of surgery. The instability will likely cause failure of the cartilage restoration procedure. The most common treatments performed for chondral injury are chondroplasty and microfracture. The main reason is these procedures are inexpensive and technically less challenging than the other procedures. Most surgeons have learned these procedures during their residency and fellowships. Generally, we reserve these procedures for small lesions less than 1 cm and in areas where there is not much loading. The goal of microfracture is to drill into the subchondral bone and release mesenchymal stem cells that fill the lesion with fibrocartilage or type 1 collagen, Bone marrow stimulation technique (Figure 6). We rarely do microfracture in our practice because most of the smaller lesions are asymptomatic and we treat conservatively. There has been advancement in the technique of microfracture in recent years by adding a scaffold to create an enhanced chondrogenic environment[43]. We only treat symptomatic patients who generally have larger lesions in loading areas of the knee. Small lesions in areas of high load, we treat with osteochondral autografts (OATS). The OATS procedure is transferring healthy cartilage from a non-weight bearing of the knee to a chondral defect in the weight bearing area of the knee. The OATS is limited by donor availability and limited to smaller lesions. Studies demonstrate that the OATS procedure is superior to a microfracture technique in the treatment of smaller load bearing defects[44]. In our practice and most of our patients have moderate to large lesions generally over 2 cm^2. Osteochondral allografts are the treatment of choice for patients with significant damage to the osteochondral unit and injury that results in significant subchondral bone loss or subchondral changes. Utilization of an osteochondral allograft for a large cartilage lesion is considered a salvage procedure. Studies have shown a graft survival rate of 79% at 10 years, and 73% at 15 years[35] (Figure 7).

Our preference for large lesions without significant bony involvement is a cellular based repair technique such as the MACI. Matrix-associated chondrocyte implantation procedures should be considered in patients between ages 15-55 with large, full-thickness defects that less than 6 mm in depth. Despite the disadvantages of being a staged procedure

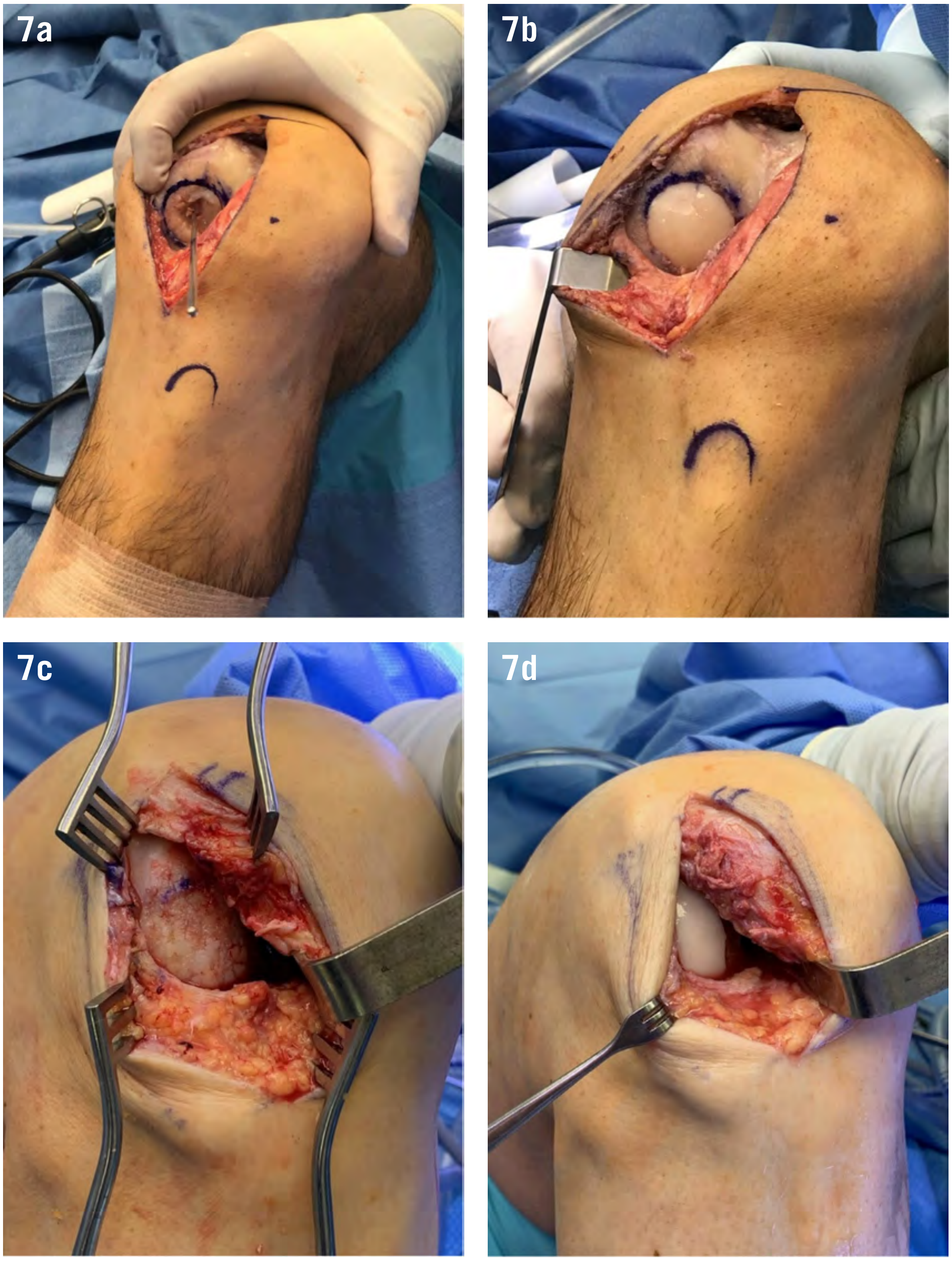

Figure 7: (a and b) Osteochondral allograft. (c and d) Osteochondral allograft – biological unicondylar allograft.

and added cost, the technique is bone preserving and allows the ability to treat lesions of a variety of sizes, shapes, and locations[36]. Since the first generation of autologous chondrocyte implantation techniques of the late 1990s, there have been significant technical advancements in this procedure. Modern day third generation techniques allow efficient, uniform distribution of cell density across the ACI membrane, while also providing an improved delivery mechanism to allow even delivery of the chondrocytes to the defect[37]. Several level 1 and 2 studies have demonstrated improved long-term outcomes in patients with MACI procedures over those with microfracture[38,39] (Figure 8).

CONCLUSION

In conclusion, joint restoration surgery is challenging and should be delayed and deferred for as long as possible through activity modification, weight loss, and physical therapy. When non-surgical options have been exhausted, the treating physician should have a thorough understanding of the intimate relationship between biology, biomechanics, and the technical ability to identify and correct the respective pathology. Corrective osteotomies, ligamentous repairs, and meniscal transplants are the variables that promote longevity in concomitant osteochondral procedures.

Figure 8: MACI procedure.

Appendix I: KEY FACTORS TO SUCCESS

1. ***Patient Factors: Age, activities, and expectations***
   a. Rehab potential

2. ***Lesion Factors:***
   a. Location: - weight bearing area and patellofemoral joint
   b. Size: Greater than 2cm²
   i. Smaller lesions: possibly asymptomatic
   c. Depth: amount of bone involvement

3. ***Comorbidities: Surgeon must be comfortable with these PROCEDURES:***
   a. Alignment
   i. Osteotomies
   b. Instability
   i. ACL
   ii. Multiligament injuries
   c. Meniscal pathology
   i. Meniscal transplantation
4. ***Cartilage technique***
   a. Bone marrow stimulation: smaller and possible with scaffold
   b. Osteochondral autograft vs. allograft
   i. Choice depends on size of lesion and availability of donor site
   c. Cellular based technique
   i. MACI
   1. 2 stages
   2. Workhorse for PFJ

References

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