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INJURIES IN OVERHEAD ATHLETES (J DINES AND C CAMP, SECTION EDITORS)

Osteochondritis dissecans lesions of the capitellum in overhead athletes: a review of current evidence and proposed treatment algorithm

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Abstract

Purpose of the Review To review the most recent literature on osteochondritis dissecans (OCD) lesions of the capitellum in overhead athletes and describe a treatment algorithm based on current best evidence and surgeon experience.

Recent Findings Recent research has included larger cohort studies with longer follow-up as well as quality systematic reviews and meta-analyses. These studies have focused on understanding how lesion characteristics such as size, location, and appearance on advanced imaging can predict treatment success. Current literature continues to support nonoperative management for stable lesions. Operative intervention is generally required for unstable lesions and treatment strategies are largely dictated by lesion size and location: debridement or reparative techniques for small lesions while larger lesions or those in high-stress locations are better served by bone and/or cartilage restoration procedures. There has been a rising interest in the use of allograft materials and cell-based therapies.

Summary Overhead athletes are uniquely predisposed to capitellar OCD due to the nature of forces applied to the radiocapitellar joint during repeated activity in the overhead position. Despite improvements in operative techniques, successful use of alternative graft materials, and a better understanding of how lesion characteristics influence results, there is still much to learn about this challenging disorder. Future research should focus on comparing operative techniques, refining their indications, and further developing a reliable treatment algorithm that best serves the overhead athlete.

Keywords Osteochondritis dissecans (OCD) · Humeral capitellum · Overhead athlete · Elbow pain · Baseball players · Gymnasts

Introduction

The term osteochondritis dissecans (OCD) was originally coined by Konig in 1888 to describe the presence of intra-articular loose bodies without known antecedent trauma [1–3]. While the exact mechanism for OCD lesion formation remains unclear, a multi-factorial etiology—altered biomechanics, repetitive microtrauma, localized ischemia, and a genetic predisposition—is most likely [4–7]. When specifically assessing OCD of the capitellum, repetitive compression at the radiocapitellar articulation from either excessive valgus or axial loading is believed to play the predominant role [8]. Therefore, while capitellar OCD lesions have been described in athletes playing handball, basketball, kendo, lacrosse, and motocross, it is the overhead athlete—baseball players and gymnasts—who are most commonly affected by this disorder [3, 8, 9]. In fact, the highest reported incidence is in youth baseball players ranges between 1 and 7% [10–12].

Inherent differences in overhead sport alter how forces are applied to the radiocapitellar joint, thereby changing the location of OCD lesions on the capitellum. In baseball, for example, the elbow is positioned in 30–90° of flexion during the early acceleration phase of throwing and simultaneously subjected to a significant valgus load [13]. Conversely, gymnasts often weight-bear in an overhead position characterized by maximum elbow extension and an almost purely axially directed force. As a result, OCD lesions in gymnasts tend to occur about 30° more posterior on the capitellum compared to those in baseball players [9]. The correlation between overhead sport and OCD lesion location is an important

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consideration for the operating surgeon when identifying lesions on diagnostic imaging, preparing a treatment strategy and planning the surgical approach [9].

Clinical Presentation

Patients with capitellar OCD typically present with progressively worsening pain over the lateral aspect of the elbow, decreased range of motion (ROM), and mechanical symptoms that may interfere with athletic performance [3, 4, 14]. These findings are almost exclusive to the dominant arm [8, 15]. In a study performed by Kida et al. [11], 32.9% of baseball players had elbow pain when throwing at the time of their diagnosis and 81.7% reported a history of prior elbow pain when throwing. Similarly, Otoshi et al. [12] found that 77.4% of the patients in their study with a diagnosis of capitellar OCD reported a history of elbow pain. On physical exam, the most common finding is tenderness over the radiocapitellar joint or capitellum with the elbow maximally flexed. Crepitus with pronation and supination may also be noted and loading the joint with a radiocapitellar shear test (resisted extension with the hand in full pronation) reproduces the symptoms [16]. Flexion contractures averaging 15–30° can be seen in advanced cases [17].

Imaging

Imaging studies are an important aspect of evaluating a young athlete with a clinical presentation suspicious for capitellar OCD. Routine orthogonal x-rays may miss roughly half of all OCD lesions [18]. An anteroposterior radiograph with the elbow in 45° of flexion may help with visualization [18, 19]; however, ultrasonography is perhaps a better initial screening tool and is capable of identifying even asymptomatic or minimally symptomatic lesions [10, 20]. Advanced imaging—computed tomography (CT) and magnetic resonance imaging (MRI)—is the most valuable imaging `study for identifying capitellar OCD lesions. CT studies are useful for characterizing lesion displacement and the geography of loose bodies, while MRI can nicely depict early-stage lesions by highlighting bone marrow changes or cartilage fragmentation [20].

X-rays, CT, and MRI all have a role in identifying lesions and in determining lesion stability, an important consideration for determining nonoperative or operative treatment. Radiographic features of a stable lesion include flattening and radiolucency [18, 21, 22]. Any signs of sclerosis or fragmentation are features of unstable lesions. Features of unstable lesions on MRI include fluid imbibition at progeny fragment, increased T2 signal at interface of progeny and parent bone, sclerosis of donor bed, and any crack or break in cartilage surface (Fig. 1) [22]. MRI staging systems have also been developed to provide accurate and reliable estimates of a lesion's International Cartilage Repair Society (ICRS) classification (Table 1), a system recognized as precisely characterizing lesion stability based on the arthroscopic interrogation of lesions [22, 23].

Classification

Staging OCD lesions during the initial patient evaluation is important because lesion stage influences both treatment choice and prognosis. The most widely used classifications systems can be found in Table 1 and Table 2. Additionally, Johnson et al. [5] recently developed a unique system of lesion localization based on a clock face that intends to more precisely describe lesion location. The intent of this system is to help facilitate intraoperative decision-making and permit longitudinal follow-up for clinical and research purposes.

The following sections will focus on conservative and operative treatment strategies for capitellar OCD lesions. A treatment algorithm will be proposed using information gathered from review of the literature and the authors' personal experience treating this challenging disorder.

Conservative Management

Description and Indications

While our understanding of the natural progression of capitellar OCD remains incomplete, the literature has shown that certain lesions have the capacity to spontaneously heal, particularly in the skeletally immature patient. Patients who have a known stable lesion should be offered conservative treatment. This consists of rest and avoidance of activities such as throwing, push-ups, arm wrestling, and weight lifting [24–26, 27••]. Elbow bracing may also be utilized for a short period of time [3, 14]. New imaging should be obtained after 3–6 months of conservative treatment. If radiographic improvement is observed and the patient is asymptomatic, sport-specific training can be reasonably resumed [3, 17]. However, if the lesion is unchanged or worse, surgical treatment may be considered [17, 24, 25]. Longer or multiple trials of conservative treatment may be reasonable to attempt in patients with closed physes, especially if the lesions are of lower stage, given their high potential for spontaneous healing [24].

Results

In a study performed by Takahara et al., 9/17 (53%) patients with nondisplaced lesions and 4/7 (57%) patients with advanced lesions, defined as OCD lesions demonstrating displacement, had poor subjective results at the last examination with nonoperative management. When investigating radiographic improvement, 2/5 (40%) lesions in elbows with open

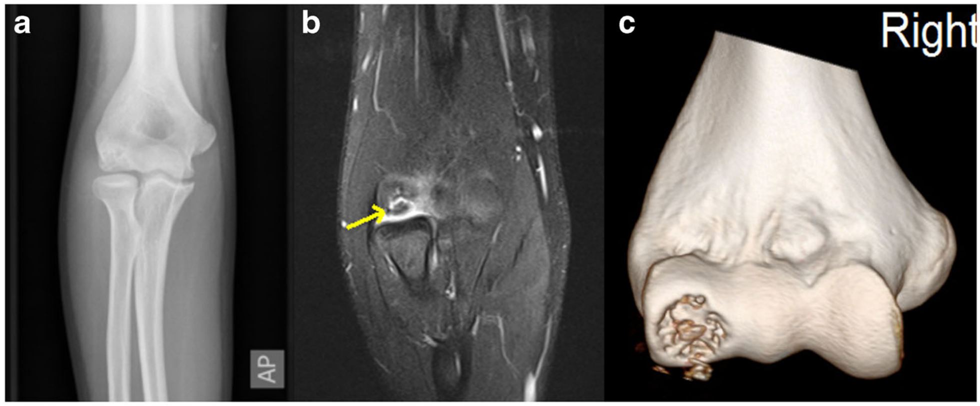

Fig. 1 Large unstable lesion of the capitellum with a detached progeny fragment as depicted on radiograph (**a**), MRI (**b**), and computed tomography imaging (**c**)

physes, 4/10 lesions (40%) in elbows with closed physes, and 6/11 (55%) patients with nondisplaced lesions showed radiographic improvement or were healed, while no patients (0/4) with advanced lesions showed any improvement [26]. In a study of 39 patients performed by Mihara et al., final radiography of the 26 patients with a grade 1 lesion revealed 20/26 patients who were completely healed, 3/26 patients who were almost healed, and the remaining patients with lesion progression. Among the 9 patients with advanced lesions, 1/9 healed, 6/9 were assessed as unimproved, 1/9 was assessed as not healed but improved, and 1/9 progressed. In patients with open physes, 16/17 (94%) patients were healed while only 11/22 (50%) patients with closed physes were healed [24]. Similarly, Matsuura et al. looked at 101 patients treated nonoperatively and 76/84 (90.5%) with a stage 1 lesion and 9/17 (52.9%) with a stage 2 lesion were healed at final follow-up. Interestingly, of the 75 patients with similar lesions, those who did not adhere to physician recommendations only 22.7% healed [20]. On the whole, this information indicates that patients who present sooner have an early-stage lesion, and those who have open physes are highly likely to heal via nonoperative treatment when they abide by recommended restrictions.

Table 1 ICRS Osteochondritis Dissecans Lesion Classification System

Minami Classification (X-ray)	ICRS Classification (arthroscopic)	Maruyama Classification (ultrasonography)
I. Localized flattening or radiolucency	1. Stable lesions with a continuous but softened area covered by intact cartilage	1. Localized subchondral bone flattening and cartilaginous thickening
II. Nondisplaced fragment	2. Lesions with partial discontinuity that are stable when probed 3. Lesions with a complete discontinuity that are not yet dislocated (“dead in situ”)	2. Nondisplaced fragments and an intact articular surface
III. Displaced or detached fragment	4. Empty defects as well as defects with a dislocated fragment or a loose fragment	3. Displaced fragments 4. Osteochondral defects

Operative Management

There are multiple surgical options available to address OCD lesions of the capitellum in the overhead athlete. However, since the vast majority of these lesions go on to heal with conservative management alone, it is necessary to discuss when operative management is appropriate. General indications include (1) failure of conservative management, (2) unstable lesions, (3) presence of mechanical symptoms and/or loose bodies, and (4) pain in the context of daily activities.

Mechanical symptoms are an indication that an anatomic barrier (e.g., osteochondral flap or loose body) is disrupting normal joint mechanics. Stable lesions do not impede the normal arc of ulnohumeral motion, while unstable lesions commonly restrict elbow motion by 20° or more [14, 25]. Accordingly, these are unlikely to resolve without surgical intervention (Fig. 2). OCD pain is also reproducible with overhead activity but does not usually interrupt daily activities. Should pain and dysfunction be a daily part of the young athlete’s life, earlier discussion of surgical management is reasonable. As always, goals of operative treatment should be to relieve pain and eliminate symptoms, return athletes to their sport, and preserve the future function of the elbow.

Cartilage Reparative Techniques—from Debridement to Microfracture to Fixation

Description and Indications

Arthroscopic debridement, loose body excision, drilling (retrograde or anterograde), and microfracture remain viable options for select capitellar OCD lesions. Drilling is performed by using Kirschner wires to drill multiple, small holes in the

Table 2 Kolmodin et al. classification system

Grade	Description
1	Open capitellar physis, a grade I radiographic lesion, and nearly full range of motion (ROM)
2	Closed capitellar physis, a grade II/III lesion radiographically or present with restricted elbow ROM, and the lesion lies medial to the radial head center line
3a	Closed capitellar physis, a grade II/III lesion radiographically or present with restricted elbow ROM, and the lesion lies laterally to the radial head center line
3b	Closed capitellar physis, a grade II/III lesion radiographically or present with restricted elbow ROM, and the lesion lies laterally to the radial head center line including the lateral cartilage margin

subchondral bone to stimulate a biologic response and healing [28]. This is most commonly performed when there is failure of healing of the subchondral bone, but the overlying cartilage is intact. When the cartilage is compromised, debridement is often considered (Fig. 2). Debridement involves the removal of unstable cartilage and necrotic bone via a curette or shaver [29]. Microfracture involves the use of an awl to impact below the level of the subchondral bone enough to allow marrow elements to egress into the lesion bed. Simple debridement or drilling may be indicated for ICRS stage 1 lesions that fail nonoperative treatment. Microfracture is often indicated for patients who present with ICRS stage II or III lesions that are less than or equal to 10 mm in diameter and show an intact lateral buttress of capitellar cartilage (Fig. 3) [4].

For lesions that demonstrate displaced chondral fragments, but the fragments are intact and robust (especially if the subchondral bone is attached to the fragment), consideration can be given to fixation of the progeny fragment. If the cavitary defect is greater than the subchondral component of the displaced OCD fragment, bone graft is used for filling with the chondral piece fixed over the top. Fixation has been achieved in an open or arthroscopic fashion by a number of methods including sutures, pins, darts, small anchors, or bone-peg grafts [8, 30–37]. Of note, this is the only reparative technique that attempts to restore the articular surface with patient's native hyaline tissue.

Results

In a study performed by Bexkens et al., 71 patients underwent arthroscopic debridement and microfracture and had a mean postoperative Oxford Elbow Score (OES) of 40.8. Despite a satisfactory clinical score, only 55% of patients returned to their primary sport at the same or higher level. Similar to results of patients treated nonoperatively, their study also showed that those patients with an open capitellar growth plate had more favorable outcomes compared to skeletally mature patients. Additional factors that were shown to correlate with improved outcomes were loose body removal and shorter duration of preoperative symptoms [29].

In a study performed by Tis et al., patients underwent arthroscopic debridement, drilling, or loose body removal. The majority of patients gained elbow ROM and relief of pain and/or swelling; however, only a minority were able to return to competitive sport [38]. Lewine et al. reported outcomes of 21 patients following arthroscopic drilling or microfracture of ICRS grade 4 capitellar OCD lesions. All patients initially presented with pain and 43% reported pain postoperatively. ROM also improved as mean elbow flexion contracture decreased from 15.3 to 3.19° postoperatively and mean elbow flexion increased from 128.3 to 137.1°. It was found that 85.7% of patients returned to any sport while 66.7% were able to return to their primary sport [28].

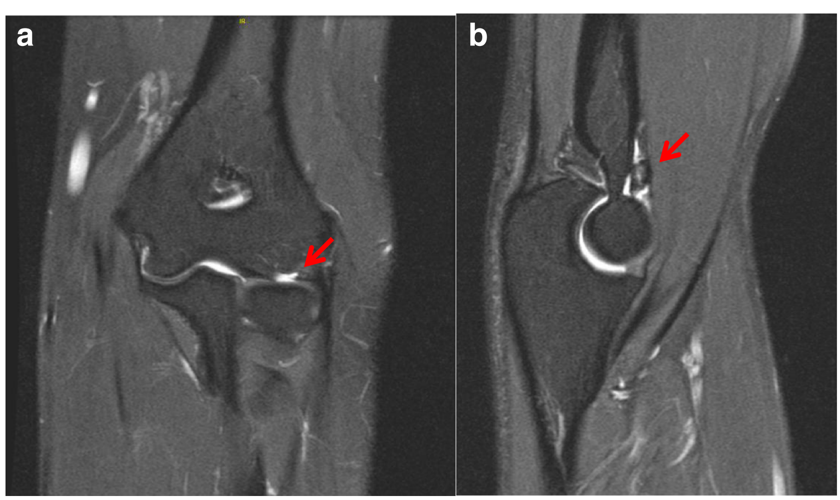

Fig. 2 Patient presenting with intermittent episodes of severe pain, catching, and locking of the elbow. Patient has a small, contained lesion (intact lateral buttress) (**a**) and an intra-articular loose body anterior to the distal humerus (**b**). This patient ultimately underwent loose body excision and simple debridement

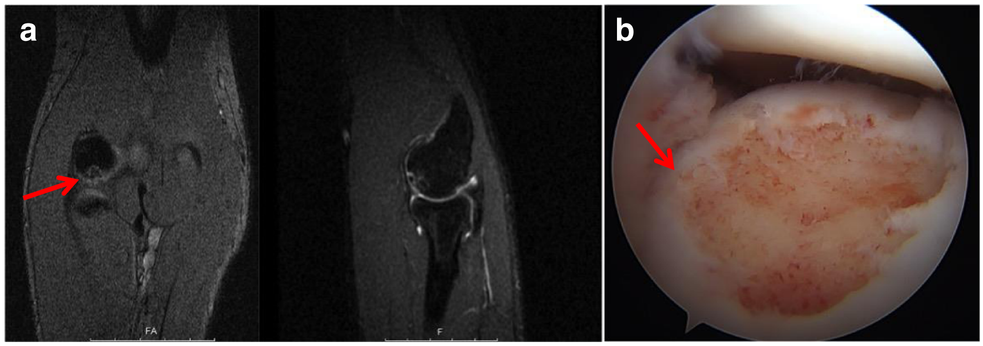

Fig. 3 OCD lesion with an intact lateral buttress (arrow) seen on MRI (**a**) and intraoperatively during arthroscopy with the patient in supine position (**b**)

Initial satisfactory outcomes after simple debridement, microfracture or drilling, and removal of loose bodies may not endure over time [3]. Thus, some authors have attempted to augment marrow-stimulating techniques with such measures as allogeneic cartilage scaffolds in an effort to promote a more hyaline-like repair and minimize long-term degenerative changes [39]. Many others depend on the long-used method of fragment fixation to achieve this; fragment fixation has historically produced reliably good outcomes and rates of union [35–37]. More recently, Maruyama et al. reported on the use of open bone-peg grafting for ICRS II lesions and reported good results at 2 years, while Uchida et al. performed arthroscopic fragment fixation using absorbable thread pins on mostly ICRS grade III lesions and achieved comparably good results at 3 years [31]. When a systematic review by Lu et al. was performed in 2018 to compare outcomes after open or arthroscopic fragment fixation, these authors found the only significant difference to be the overall rate of osseous union, 87.4% versus 97.1%, respectively. They conclude that while both arthroscopic and open methods of fragment fixation lead to high return to play (RTP) rates and improvements in motion and function, arthroscopic fixation may be a better choice pending further research and higher level data [8]. A limitation of fragment fixation may be in restoring large, lateral capitellar lesions; in these instances, other restorative options, such as osteochondral autograft transfer (OAT), appear to be a better choice [40].

Cartilage Restoration Techniques

Osteochondral Autograft Transfer

Description and Indications

First described for focal chondral and osteochondral defects of the knee [41], OAT has adapted to treat OCD lesions in the radiocapitellar joint.

OAT involves harvesting a cylindrical autograft plug of cartilage and subchondral bone from a non-weight-bearing chondral surface. One or multiple plugs can be taken. The lateral trochlear ridge of the knee is most commonly used and is accessed through a mini-open arthrotomy. The shape of the plug can be trimmed to match the exact geography of the recipient site, but cartilage thickness of the plug is difficult to customize. For this reason, some have endorsed the inferior medial trochlear ridge of the knee as a site with better matched cartilage thickness from MRI mapping studies [42]. Additionally, use of an osteochondral plug from the 5th or 6th rib, first described in the temporomandibular joint [43], has more recently been applied to the elbow [44]. Reported benefits include a broader donor surface to permit larger plug harvesting, less donor site morbidity, and a similar composition to the subchondral bone and cartilage present in synovial joints like the knee. Autograft rib plugs have proven to be a reasonable alternative source for the surgeon who is comfortable with the costal anatomy and who understands the potential risks of violating the thoracic cavity and underlying pleura [6, 44, 45].

Regardless of donor site chosen, the procedure is completed by transplanting the osteochondral plug into the bed of the lesion in a press-fit fashion. While this is routinely accomplished through a mini-open elbow arthrotomy, Gancarczyk et al. [7] has demonstrated successful arthroscopic transplantation in a cadaveric model. Supplemental fixation with Kirschner wires, compression screws, or headless screws has been described [46••, 47]. The principal advantage of OAT is that the transplanted tissue re-introduces fresh hyaline cartilage into the joint rather than the fibrocartilage product generated by marrow-stimulating techniques. Hyaline cartilage is thought to more closely recreate the native bearing surface with a more biomechanically appropriate chondral material capable of resisting the repetitive axial and shear forces at this articulation [7, 24, 48, 49].

While marrow-stimulating methods are sufficient for management of unstable lesions with a small footprint, OAT is preferable for reconstruction of unstable lesions of larger size, in patients with closed physes, or when the lateral buttress of capitellar cartilage is compromised. OCD lesion size of greater than 10–12 mm [25, 35, 49] or 50% of the capitellar articular surface are commonly reported thresholds for moving away from simple reparative techniques in favor of restorative procedures such as OAT or osteochondral allograft transplantation (OCA) [31, 47, 50].

Additionally, even small lesions may benefit from OAT or another chondral reconstructive option. Examples of such lesions include those with deficient or necrotic subchondral bone, large subchondral cysts, or lesions extending to the lateral-most articular margin of the capitellum [4]. In these instances, reparative techniques are incapable of rebuilding the supportive bone stock necessary to create a stable cartilage bed [51] and of withstanding the increased contact forces "seen" in the lateral joint. Collectively, this could lead to radial head disengagement [13, 17].

Results

Knee-to-Elbow OAT The vast majority of patients who undergo knee-to-elbow OAT have excellent results at short- and medium-term follow-up [48, 52]. Iwasaki and colleagues reported on 19 baseball players who underwent OAT for defects averaging 147 mm^2 at a mean follow-up of 45 months and found statistically significant improvements in Timmerman and Andrews (T&A) scores, elbow motion, pain relief (95% of patients), and a 90% RTP rate [52]. Similar postoperative improvements were found in much larger series, albeit with shorter follow-up [27••, 49, 53]. Long-term follow-up after OAT reconstruction is currently lacking with only one study of 8 patients showing excellent clinical and radiographic results at 10 years comparable to midterm results [54].

Some studies describing OAT cohorts where fewer, larger plugs were transplanted, rather than mosaicplasty (the use of many small plugs), have reported quicker RTP [48]. Proponents hypothesize that larger and fewer grafts result in greater graft stability and faster osseous union, an effect demonstrated in the OAT literature for cartilage defects of the knee [55]. While a reasonable postulation, a recent systematic review on the topic did not find enough evidence to support an association between number of grafts or graft size and RTP [56••]. Every effort should be made to restore congruity of the articular cartilage surface, regardless of the number of plugs utilized.

Lesion size and location influence OAT outcomes, with larger and more laterally located lesions considered more severe and difficult to treat [13, 27••, 40, 48, 49, 57]. Johnson et al. [5] found roughly 1/3 of capitellar OCD lesions to be laterally located. When comparing 44 laterally located lesions to 43 centrally located lesions, Matsuura and colleagues [27••] found central lesions to fare better in terms of postoperative T&A scores, incidence of radial head subluxation, and RTP. A greater proportion of contact pressure occurring in the lateral radiocapitellar joint during throwing, thereby increasing stress on the autograft repair, is thought to contribute to this [13]. Regardless, OAT for lateral lesions in this study still performed well (mean T&A score 48.6 compared to 54.1 for central lesions and 86% RTP compared to 100% for central lesions). Thus, when treating lateral OCD lesions, operating surgeons should be aware of the risk of an inferior result, pay meticulous attention to graft selection, and make every attempt to reconstruct the lateral capitellar margin with a well-rounded, durable, and well-fixed graft [40].

Rib-to-Elbow OAT Rib-to-elbow OAT has produced comparable results when compared to knee-to-elbow OAT [13, 35, 43–47]. Sato et al. recently published the largest series, 72 patients, treated with costal osteochondral grafts for capitellar OCD. Fifty-two of the lesions were laterally located. At a minimum 3-year final follow-up, improvements were observed in extension/flexion (−21/122° to −4/136°) and T&A scores (101 to 190) compared to preoperative. Radiographic union was achieved for all by 3 months and 97% RTP at mean of 5.8 months. Prior smaller studies demonstrated similarly excellent improvements in ROM and clinical outcomes with a 100% return to play in 6–7.5 months [45, 47].

Return to Play The goal of many overhead athletes who undergo OAT for OCD lesions of the capitellum is successful return to their pre-injury level of competition. A systematic review including 7 level IV studies specifically looking at RTP after OAT found 94% of all patients return to competitive athletics without restrictions at a mean of 5.6 months (range, 3–14 months). While this review consists of studies of varying lesion characteristics and non-uniform surgical techniques and postoperative protocols, it provides the current best evidence to support this surgical treatment modality in the young overhead athlete.

In summary, both knee- and rib-to-elbow OATs produce reliably good results and have a higher likelihood of RTP than more conservative operative techniques. These procedures are therefore currently some of the most effective treatment modalities available for unstable OCD lesions of the capitellum.

Donor Site Morbidity

The reported rate of knee donor site morbidity is roughly 8% [58]. Reported symptoms include knee effusions lasting an average of 3 weeks, knee pain with stair climbing or heavy activity, a locking sensation, and muscle deconditioning improved by 1 year [49, 59–61].

In 2001, Oka and Ikeda suggested the rib could be an autograft source with minimal donor site morbidity [45]. Since, other authors have reported good results and low morbidity using this donor site [13, 35, 43, 45–47]. A 2017 systematic review and meta-analysis by Bexkens et al. comparing donor site morbidity from knee and rib sources found a lower rate (1.6% or 1/62 patients) in the rib OAT procedures. The single complication was a pneumothorax that resolved with chest tube insertion [47].

Osteochondral Allograft Transplantation

Description and Indications

Mirzayan and Lim are credited for the first report of fresh osteochondral allograft transplantation (OCA) for OCD lesions in the elbow [62]. While acknowledging the encouraging short-term results of OAT, these authors recognized some patients and parents may be averse to undergoing a harvesting procedure on an asymptomatic, juvenile knee. As an alternative, OCA grafts can be obtained from a fresh-stored cadaveric capitellum or femoral condyle. OCA retains most major benefits of OAT, namely augmentation of subchondral bone stock and articular reconstruction with hyaline cartilage, while eliminating this issue of donor site morbidity. OCA has a well-described use for chondral and osteochondral defects of the knee with 80% graft survival noted in adults and as high as 90% in children and adolescents at 10 years [63–65]. While the application of OCA to the elbow is still in its early stages, results thus far have been promising (Fig. 4).

Results

In the germinal study by Mirzayan and Lim, 9 baseball players underwent OCA with an average follow-up of 48.3 months [62]. One plug was used in 7 patients, while 2 plugs were necessary in 2 patients; average plug diameter was 10.75 mm. They reported significant improvement in pain and all clinical outcome scores. Further, all patients returned to their former level of play. While further investigation is needed, current evidence supports the use of allograft tissue and OCA in the elbow when donor site morbidity is a concern or barrier to surgical intervention.

Autologous Chondrocyte Implantation

Description and Indications

Autologous chondrocyte implantation (ACI) is a chondral reconstructive technique that was first developed to treat chondral and osteochondral defects of the knee and ankle joints [35, 66–69]. This procedure involves arthroscopically harvesting cartilage near the site of OCD lesion, enzymatically isolating chondrocytes in vitro, cultivating the chondrocytes with ex vivo expansion, and then returning to the operative suite for implantation of the chondrocytes into the OCD cartilage defect. Slight variations in harvesting, cultivation, and operative technique have been described, but the primary principles, originally described by Sato et al., remain largely unchanged [70–72]. Benefits of ACI include a hyaline cartilage phenotype and an all-arthroscopic procedure. Disadvantages include cost, no restoration of subchondral bone, and a staged operation with a 3–8-week time interval necessary for chondrocyte cultivation before definitive management [70, 72].

Results

The first reported use of this procedure for elbow OCD was a single case report describing a 1 × 1.8-cm treated defect with excellent clinical results at 2-year follow-up [70]. Iwasaki et al. subsequently authored a case report of 2 patients who were followed for just over 4 years, one of which was an overhead athlete [73]. After failing fragment excision of an unstable lesion measuring 1.4 × 2.1 cm, the patient had no pain and improved ROM (total arc, 95° to 125°) and Mayo Elbow Performance Index scores (65/100 to 100/100). Since this report, only two other publications on the use of ACI for capitellar OCD have been written to our knowledge: a single case report of a 40-year-old non-competitive athlete and a technique article [71, 72]. Because ACI requires that the

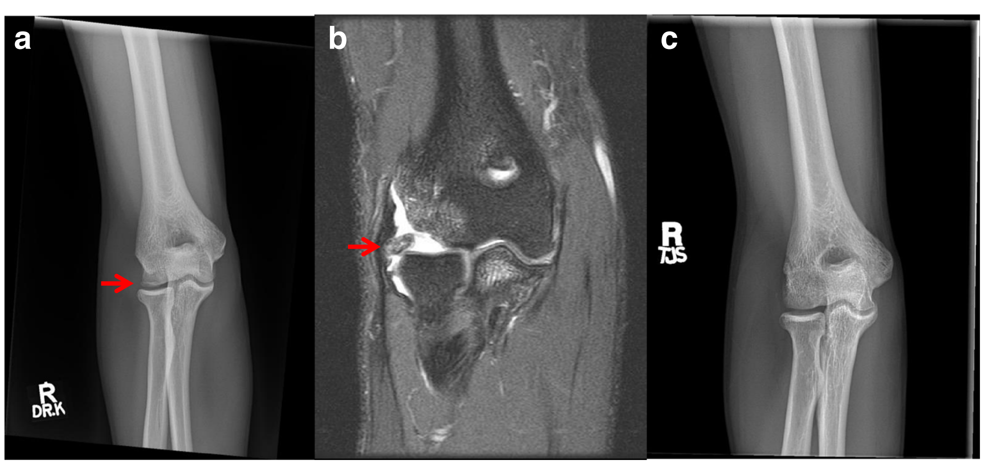

Fig. 4 Preoperative radiograph (**a**) and MRI demonstrating a large uncontained defect with violated lateral buttress. Lesion was treated with osteochondral allograft transplantation (OCA) (**c**)

subchondral bone remain intact, and by definition, OCD lesions involve both the cartilage and the underlying bone, the role for ACI in capitellar OCD is currently limited.

Postoperative Care and Rehabilitation

Surgery for capitellar OCD is performed on an outpatient basis in most instances. Afterwards, however, approaches to postoperative rehabilitation vary considerably. Postoperative recovery and rehabilitation occurs in 4 phases. Although there is some overlap between the phases, the order is typically (1) healing/immobilization, (2) motion, (3) strengthening, and finally (4) sport-specific training:

1) Healing/immobilization: time for this varies and largely depends on the soft tissue dissection required. For arthroscopic debridement or microfracture, immobilization is not routinely used [4, 25, 29, 38, 51, 74]. For larger procedures, operative extremities may be immobilized in a sling for up to 2–3 weeks but rarely longer. Some authors immobilize in a long-arm splint or cast [27••, 40, 45–49, 52, 70, 72].
2) Motion: our practice is to begin motion as soon as soft tissues allow [4, 38]. Patients start with small arcs of motion and gradually increase as able. The goal is generally full ROM by 6–8 weeks postoperatively [4]. Guidance by a trained physical therapist is advocated by some during this process [29, 62].
3) Strengthening: timing depends on the procedure performed. Shoulder isometrics are typically permitted within the first few weeks after surgery. For larger cases, elbow isometrics may begin once elbow ROM is restored. Strengthening is progressed as able.
4) Sport-specific training: it is important not to neglect the rest of the body during elbow recovery. Accordingly, lower extremity, core, and cardiovascular exercises are initiated as soon as possible after surgery. For simple debridement and microfracture, return to sport-specific training typically begins as soon as symptoms permit, usually around 1–3 months. For larger restorative procedures such as OAT or OCA, return is delayed until bone is healed on imaging (X-ray, CT, or MRI), usually around 6 months [25, 27••, 40, 45–49, 52, 62]. Full return to previous level of throwing and sporting activity is usually suggested no earlier than 6 months [25, 27••, 40, 46••, 47, 49, 62]. Lesion location- [27••] and baseball position-specific [47, 52] rehabilitation protocols have been described.

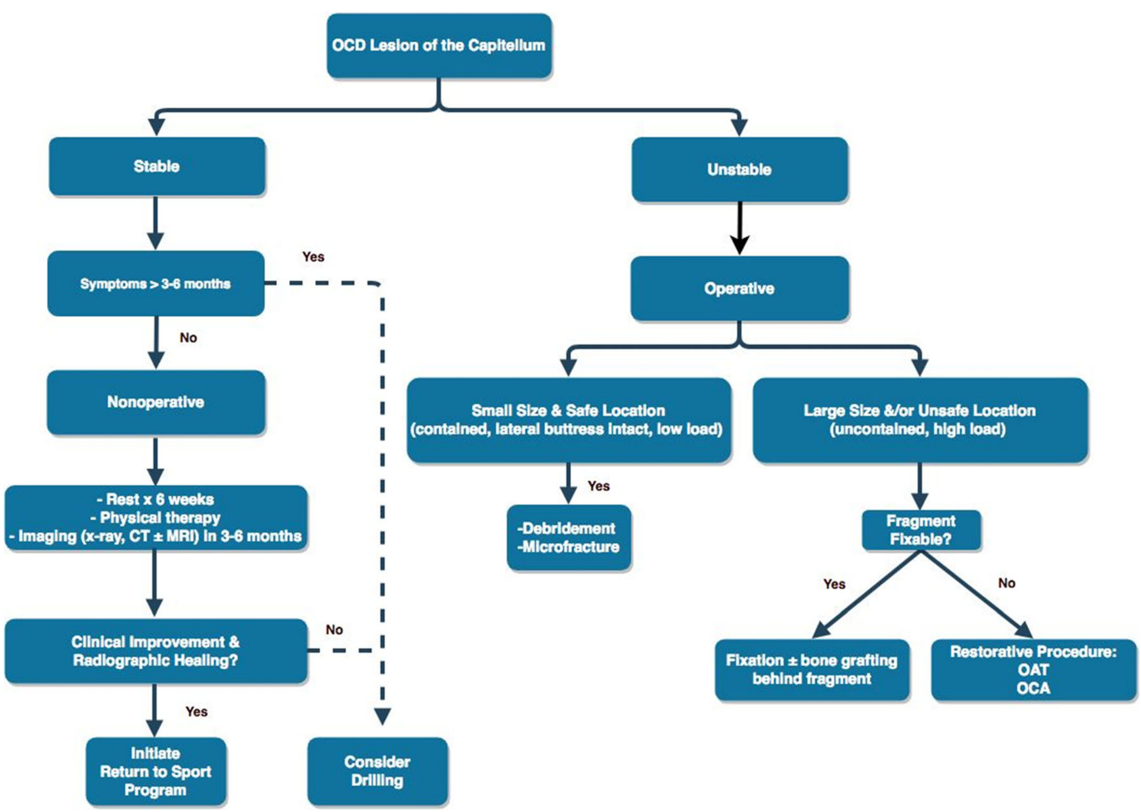

Fig. 5 Preferred treatment algorithm for capitellar osteochondritis dissecans (OCD) lesions. ICRS, International Cartilage Rating System; OAT, osteochondral autograft transfer; OCA, osteochondral allograft transplantation; COT, costal osteochondral transfer; ACI, allogeneic chondrocyte implantation. Greater number of "+" indicates a greater preference to use the indicated surgical technique

Authors' Preferred Treatment Approach

Having a consistent, strategic approach is critical to clinical management and future study of this challenging disorder. Figure 5 depicts the authors' preferred treatment approach based on the available literature and previous experience in treating OCD lesions in overhead athletes. Other authors have described comparable treatment algorithms [25, 47, 48]. It is important to note, however, that every patient should be approached on an individual basis as not all patients fit neatly into the algorithm provided. This algorithm is intended to serve as a general guideline, but treatment should be individualized to the specific patient based on their activity level, demands, specific lesion characteristics, symptom duration, and goals.

Notably absent from this treatment algorithm is closed-wedge osteotomy of the capitellum. This has been described as both a primary procedure and a way to augment chondral resurfacing techniques. The intended effect is to widen the radiocapitellar space and decrease the compressive loads at this articulation, as well as to stimulate local blood flow during osteotomy healing [75]. Due to lack of evidence and unsatisfactory long-term outcomes by current methods, the role of this procedure and its place in the treatment algorithm for capitellar OCD in the overhead athlete are unclear.

Future Directions

While current knowledge of OCD lesions of the capitellum and data supporting optimal treatment strategies has grown in the last few decades, there is still much to learn about this common problem [1]. Specifically, the field of joint surface restoration in the elbow—namely, OAT, OCA, and ACI—is in its infancy. While we have several procedures available, higher level, comparative studies are needed to establish concrete indications. A direct comparison of knee and rib autograft procedures or comparison of OAT to OCA are a few examples. For most of these procedures, longer follow-up is needed to see if symptomatic improvement and RTP endure over time. Sport-specific outcomes and reviews after various surgical interventions are needed given the change in applied stresses to the radiocapitellar joint during the different overhead sports. Further investigation into postoperative care, including determining the role for immobilization and its influence on outcomes, is needed. Finally, and possibly of utmost importance, greater efforts are needed to educate young athletes and parents to the known causes of OCD. Awareness of this issue may lead to a call for earlier recognition strategies and better preventative solutions. Finally, the potential benefit of implementing a universal screening program for youth overhead athletes to identify capitellar OCD lesions early, something that has already gained support in Japan, should be investigated further [11, 20].

Conclusions

OCD of the capitellum is a rare elbow disorder predominantly affecting young, overhead athletes. While stable lesions respond well to a conservative regimen of rest and gradual return to throwing, unstable lesions, or those that fail conservative management, warrant surgery. Reparative—simple debridement, fragment excision, drilling, microfracture, and fragment fixation—and restorative solutions—OAT, OCA, and ACI—all play a role in the reconstructive surgeon's armamentarium. While we have made some headway in understanding the specific roles of each in the treatment of capitellar OCD, the algorithm will continue to be refined as more high-level research is performed comparing the described techniques.

Compliance with Ethical Standards

Conflict of Interest Anthony L. Logli, Christopher D. Bernard, and Christopher L. Camp declare no conflict of interest.

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References

Papers of particular interest, published recently, have been highlighted as:

- • Of importance
- •• Of major importance

1. Konig F. The classic: on loose bodies in the joint. 1887. Clin Orthop Relat Res. 2013;471(4):1107–15.
2. Edmonds EW, Polousky J. A review of knowledge in osteochondritis dissecans: 123 years of minimal evolution from

Konig to the ROCK study group. Clin Orthop Relat Res. 2013;471(4):1118–26.
3. Churchill RW, Munoz J, Ahmad CS. Osteochondritis dissecans of the elbow. Curr Rev Musculoskelet Med. 2016;9(2):232–9.
4. Camp CL, Dines JS, Degen RM, Sinatro AL, Altchek DW. Arthroscopic microfracture for osteochondritis dissecans lesions of the capitellum. Arthrosc Tech. 2016;5(3):e477–81.
5. Johnson CC, Roberts S, Mintz D, Fabricant PD, Hotchkiss RN, Daluiski A. Location of osteochondritis dissecans lesions of the capitellum. J Hand Surg Am. 2018;43(11):1039.e1–7.
6. Griffith TB, Kercher J, Clifton Willimon S, Perkins C, Duralde XA. Elbow injuries in the adolescent thrower. Curr Rev Musculoskelet Med. 2018;11(1):35–47.
7. Gancarczyk SM, Makhni EC, Lombardi JM, Popkin CA, Ahmad CS. Arthroscopic articular reconstruction of capitellar osteochondral defects. Am J Sports Med. 2015;43(10):2452–8.
8. Lu Y, Li YJ, Guo SY, Zhang HL. Is there any difference between open and arthroscopic treatment for osteochondritis dissecans (OCD) of the humeral capitellum: a systematic review and meta-analysis. Int Orthop. 2018;42(3):601–7.
9. Kajiyama S, Muroi S, Sugaya H, Takahashi N, Matsuki K, Kawai N, et al. Osteochondritis dissecans of the humeral capitellum in young athletes: comparison between baseball players and gymnasts. Orthop J Sports Med. 2017;5(3):2325967117692513.
10. Harada M, Takahara M, Sasaki J, Mura N, Ito T, Ogino T. Using sonography for the early detection of elbow injuries among young baseball players. AJR Am J Roentgenol. 2006;187(6):1436–41.
11. Kida Y, Morihara T, Kotoura Y, Hojo T, Tachiiri H, Sukenari T, et al. Prevalence and clinical characteristics of osteochondritis dissecans of the humeral capitellum among adolescent baseball players. Am J Sports Med. 2014;42(8):1963–71.
12. Otoshi K, Kikuchi S, Kato K, Sato R, Igari T, Kaga T, et al. Age-specific prevalence and clinical characteristics of humeral medial epicondyle apophysitis and osteochondritis dissecans: ultrasonographic assessment of 4249 players. Orthop J Sports Med. 2017;5(5):2325967117707703.
13. Mihata T, Quigley R, Robicheaux G, McGarry MH, Neo M, Lee TQ. Biomechanical characteristics of osteochondral defects of the humeral capitellum. Am J Sports Med. 2013;41(8):1909–14.
14. van Bergen CJ, van den Ende KI, Ten Brinke B, Eygendaal D. Osteochondritis dissecans of the capitellum in adolescents. World J Orthop. 2016;7(2):102–8.
15. Hennrikus WP, Miller PE, Micheli LJ, Waters PM, Bae DS. Internal fixation of unstable in situ osteochondritis dissecans lesions of the capitellum. J Pediatr Orthop. 2015;35(5):467–73.
16. Morrey BF, Sotelo JS, Morrey ME. Morrey's the elbow and its disorders E-book: Elsevier health sciences; 2017.
17. Baker CL III, Romeo AA, Baker CL Jr. Osteochondritis dissecans of the capitellum. Am J Sports Med. 2010;38(9):1917–28.
18. Kijowski R, De Smet AA. Radiography of the elbow for evaluation of patients with osteochondritis dissecans of the capitellum. Skelet Radiol. 2005;34(5):266–71.
19. Takahara M, Shundo M, Kondo M, Suzuki K, Nambu T, Ogino T. Early detection of osteochondritis dissecans of the capitellum in young baseball players. Report of three cases. JBJS. 1998;80(6):892–7.
20. Matsuura T, Suzue N, Iwame T, Nishio S, Sairyo K. Prevalence of osteochondritis dissecans of the capitellum in young baseball players: results based on ultrasonographic findings. Orthop J Sports Med. 2014;2(8):2325967114545298.
21. Claessen FM, van den Ende KI, Doornberg JN, Guitton TG, Eygendaal D, van den Bekerom MP, et al. Osteochondritis dissecans of the humeral capitellum: reliability of four classification systems using radiographs and computed tomography. J Shoulder Elb Surg. 2015;24(10):1613–8.
22. Satake H, Takahara M, Harada M, Maruyama M. Preoperative imaging criteria for unstable osteochondritis dissecans of the capitellum. Clin Orthop Relat Res. 2013;471(4):1137–43.
23. Itsubo T, Murakami N, Uemura K, Nakamura K, Hayashi M, Uchiyama S, et al. Magnetic resonance imaging staging to evaluate the stability of capitellar osteochondritis dissecans lesions. Am J Sports Med. 2014;42(8):1972–7.
24. Mihara K, Tsutsui H, Nishinaka N, Yamaguchi K. Nonoperative treatment for osteochondritis dissecans of the capitellum. Am J Sports Med. 2009;37(2):298–304.
25. Maruyama M, Takahara M, Satake H. Diagnosis and treatment of osteochondritis dissecans of the humeral capitellum. J Orthop Sci. 2018;23(2):213–9.
26. Takahara M. Nonoperative treatment of osteochondritis dissecans of the $$. 1999.
27.•• Matsuura T, Hashimoto Y, Nishino K, Nishida Y, Takahashi S, Shimada N. Comparison of clinical and radiographic outcomes between central and lateral lesions after osteochondral autograft transplantation for osteochondritis dissecans of the humeral capitellum. Am J Sports Med. 2017;45(14):3331–9 **This is the first study to compare clinical outcomes of OAT performed for central lesions to OAT performed for lateral lesions. These authors found that mean postoperative flexion/extension, Timmerman and Andrews scores, and return to sport were significantly better in the central group; elbows in the lateral group also had significantly higher postoperative radial head subluxation. This study provides convincing evidence that the behavior of central and lateral lesions is unique and that while satisfactory results can be expected for all lesions after OAT, central lesions fare better at short-term follow-up.**
28. Lewine EB, Miller PE, Micheli LJ, Waters PM, Bae DS. Early results of drilling and/or microfracture for grade IV osteochondritis dissecans of the capitellum. J Pediatr Orthop. 2016;36(8):803–9.
29. Bexkens R, van den Ende KIM, Ogink PT, van Bergen CJA, van den Bekerom MPJ, Eygendaal D. Clinical outcome after arthroscopic debridement and microfracture for osteochondritis dissecans of the capitellum. Am J Sports Med. 2017;45(10):2312–8.
30. Maruyama M, Harada M, Satake H, Uno T, Takagi M, Takahara M. Bone-peg grafting for osteochondritis dissecans of the humeral capitellum. J Orthop Surg. 2016;24(1):51–6.
31. Uchida S, Utsunomiya H, Taketa T, Sakoda S, Hatakeyama A, Nakamura T, et al. Arthroscopic fragment fixation using hydroxyapatite/poly-L-lactate acid thread pins for treating elbow osteochondritis dissecans. Am J Sports Med. 2015;43(5):1057–65.
32. Koehler SM, Walsh A, Lovy AJ, Pruzansky JS, Shukla DR, Hausman MR. Outcomes of arthroscopic treatment of osteochondritis dissecans of the capitellum and description of the technique. J Shoulder Elb Surg. 2015;24(10):1607–12.
33. Takeba J, Takahashi T, Hino K, Watanabe S, Imai H, Yamamoto H. Arthroscopic technique for fragment fixation using absorbable pins for osteochondritis dissecans of the humeral capitellum: a report of 4 cases. Knee Surg Sports Traumatol Arthrosc. 2010;18(6):831–5.
34. Jones KJ, Wiesel BB, Sankar WN, Ganley TJ. Arthroscopic management of osteochondritis dissecans of the capitellum: mid-term results in adolescent athletes. J Pediatr Orthop. 2010;30(1):8–13.
35. Takahara M, Mura N, Sasaki J, Harada M, Ogino T. Classification, treatment, and outcome of osteochondritis dissecans of the humeral capitellum. Surgical technique. J Bone Joint Surg Am. 2008;90(Suppl 2 Pt 1):47–62.
36. Harada M, Ogino T, Takahara M, Ishigaki D, Kashiwa H, Kanauchi Y. Fragment fixation with a bone graft and dynamic staples for osteochondritis dissecans of the humeral capitellum. J Shoulder Elb Surg. 2002;11(4):368–72.
37. Kuwahata Y, Inoue G. Osteochondritis dissecans of the elbow managed by Herbert screw fixation. Orthopedics. 1998;21(4):449–51.

38. Tis JE, Edmonds EW, Bastrom T, Chambers HG. Short-term results of arthroscopic treatment of osteochondritis dissecans in skeletally immature patients. J Pediatr Orthop. 2012;32(3):226–31.
39. Caldwell PE, Auerbach B, Pearson SE. Arthroscopic treatment of capitellum osteochondritis dissecans with micronized allogeneic cartilage scaffold. Arthrosc Tech. 2017;6(3):e815–e20.
40. Kosaka M, Nakase J, Takahashi R, Toratani T, Ohashi Y, Kitaoka K, et al. Outcomes and failure factors in surgical treatment for osteochondritis dissecans of the capitellum. J Pediatr Orthop. 2013;33(7):719–24.
41. Hangody L, Füles P. Autologous osteochondral mosaicplasty for the treatment of full-thickness defects of weight-bearing joints: ten years of experimental and clinical experience. JBJS. 2003;85:25–32.
42. Vezeridis AM, Bae DS. Evaluation of knee donor and elbow recipient sites for Osteochondral autologous transplantation surgery in Capitellar Osteochondritis Dissecans. Am J Sports Med. 2016;44(2):511–20.
43. Munro IR, Phillips JH, Griffin G. Growth after construction of the temporomandibular joint in children with hemifacial microsomia. Cleft Palate J. 1989;26(4):303–11.
44. Oka Y, Ikeda M. Treatment of severe osteochondritis dissecans of the elbow using osteochondral grafts from a rib. Bone Joint J. 2001;83(5):738–9.
45. Nishinaka N, Tsutsui H, Yamaguchi K, Uehara T, Nagai S, Atsumi T. Costal osteochondral autograft for reconstruction of advanced-stage osteochondritis dissecans of the capitellum. J Shoulder Elb Surg. 2014;23(12):1888–97.
46.•• Sato K, Iwamoto T, Matsumura N, Suzuki T, Nishiwaki Y, Oka Y, et al. Costal osteochondral autograft for advanced osteochondritis dissecans of the humeral capitellum in adolescent and young adult athletes: clinical outcomes with a mean follow-up of 4.8 years. JBJS, 2018;100(11):903–13 **Described a relatively large cohort of 72 patients treated with costal OAT for capitellar OCD followed for a mean of 4.8 years. These authors found significant improvements in flexion/extension, Timmerman and Andrews score, and a 97% return to original sport. Medium-term results of this study suggest costal autografts reliably produce good to excellent outcomes and should be especially considered for large ostechondral lesions located in the lateral aspect of the capitellum.**
47. Shimada K, Tanaka H, Matsumoto T, Miyake J, Higuchi H, Gamo K, et al. Cylindrical costal osteochondral autograft for reconstruction of large defects of the capitellum due to osteochondritis dissecans. J Bone Joint Surg Am. 2012;94(11):992–1002.
48. Lyons ML, Werner BC, Gluck JS, Freilich AM, Dacus AR, Diduch DR, et al. Osteochondral autograft plug transfer for treatment of osteochondritis dissecans of the capitellum in adolescent athletes. J Shoulder Elb Surg. 2015;24(7):1098–105.
49. Maruyama M, Takahara M, Harada M, Satake H, Takagi M. Outcomes of an open autologous osteochondral plug graft for capitellar osteochondritis dissecans: time to return to sports. Am J Sports Med. 2014;42(9):2122–7.
50. Miyake J, Masatomi T. Arthroscopic debridement of the humeral capitellum for osteochondritis dissecans: radiographic and clinical outcomes. J Hand Surg. 2011;36(8):1333–8.
51. Zlotolow DA, Bae DS. Osteochondral autograft transplantation in the elbow. J Hand Surg. 2014;39(2):368–72.
52. Iwasaki N, Kato H, Ishikawa J, Masuko T, Funakoshi T, Minami A. Autologous osteochondral mosaicplasty for osteochondritis dissecans of the elbow in teenage athletes. JBJS. 2009;91(10):2359–66.
53. Shimada K, Yoshida T, Nakata K, Hamada M, Akita S. Reconstruction with an osteochondral autograft for advanced osteochondritis dissecans of the elbow. Clin Orthop Relat Res. 2005;435:140–7.
54. Vogt S, Siebenlist S, Hensler D, Weigelt L, Ansah P, Woertler K, et al. Osteochondral transplantation in the elbow leads to good clinical and radiologic long-term results:an 8- to 14-year follow-up examination. Am J Sports Med. 2011;39(12):2619–25.
55. Hangody L, Dobos J, Baló E, Pánics G, Hangody LR, Berkes I. Clinical experiences with autologous osteochondral mosaicplasty in an athletic population: a 17-year prospective multicenter study. Am J Sports Med. 2010;38(6):1125–33.
56.•• Kirsch JM, Thomas JR, Khan M, Townsend WA, Lawton JN, Bedi A. Return to play after osteochondral autograft transplantation of the capitellum: a systematic review. Arthroscopy. 2017;33(7):1412–20 e1 **Level IV systematic review of 7 case series consisting of 126 patients that underwent OAT for advanced capitaller OCD lesions. Mean plug size and number of plugs used was 7.7 mm and 2.1, respectively. These authors found a 94% return to sport at a mean of 5.6 months after surgery. This is currently the most convincing evidence that OAT surgery is successful at treating advanced capitaller OCD and returning atheltes to competitive sport.**
57. Kolmodin J, Saluan P. Osteochondritis dissecans of the humeral capitellum: the significance of lesion location. Orthop J Sports Med. 2014;2(4):2325967114530840.
58. Bexkens R, Ogink PT, Doornberg JN, Kerkhoffs G, Eygendaal D, Oh LS, et al. Donor-site morbidity after osteochondral autologous transplantation for osteochondritis dissecans of the capitellum: a systematic review and meta-analysis. Knee Surg Sports Traumatol Arthrosc. 2017;25(7):2237–46.
59. Nishimura A, Morita A, Fukuda A, Kato K, Sudo A. Functional recovery of the donor knee after autologous osteochondral transplantation for capitellar osteochondritis dissecans. Am J Sports Med. 2011;39(4):838–42.
60. Weigelt L, Siebenlist S, Hensler D, Imhoff AB, Vogt S. Treatment of osteochondral lesions in the elbow: results after autologous osteochondral transplantation. Arch Orthop Trauma Surg. 2015;135(5):627–34.
61. Iwasaki N, Kato H, Kamishima T, Suenaga N, Minami A. Donor site evaluation after autologous osteochondral mosaicplasty for cartilaginous lesions of the elbow joint. Am J Sports Med. 2007;35(12):2096–100.
62. Mirzayan R, Lim MJ. Fresh osteochondral allograft transplantation for osteochondritis dissecans of the capitellum in baseball players. J Shoulder Elb Surg. 2016;25(11):1839–47.
63. Levy YD, Görtz S, Pulido PA, McCauley JC, Bugbee WD. Do fresh osteochondral allografts successfully treat femoral condyle lesions? Clin Orthop Relat Res®. 2013;471(1):231–7.
64. Lyon R, Nissen C, Liu XC, Curtin B. Can fresh osteochondral allografts restore function in juveniles with osteochondritis dissecans of the knee? Clin Orthop Relat Res®. 2013;471(4):1166–73.
65. Murphy RT, Pennock AT, Bugbee WD. Osteochondral allograft transplantation of the knee in the pediatric and adolescent population. Am J Sports Med. 2014;42(3):635–40.
66. Giannini S, Buda R, Grigolo B, Vannini F, De Franceschi L, Facchini A. The detached osteochondral fragment as a source of cells for autologous chondrocyte implantation (ACI) in the ankle joint. Osteoarthr Cartil. 2005;13(7):601–7.
67. Whittaker J-P, Smith G, Makwana N, Roberts S, Harrison P, Laing P, et al. Early results of autologous chondrocyte implantation in the talus. J Bone Joint Surg Br. 2005;87(2):179–83.
68. Peterson L, Minas T, Brittberg M, Lindahl A. Treatment of osteochondritis dissecans of the knee with autologous chondrocyte transplantation: results at two to ten years. JBJS. 2003;85:17–24.
69. Aldrian S, Zak L, Wondrasch B, Albrecht C, Stelzeneder B, Binder H, et al. Clinical and radiological long-term outcomes after matrix-induced autologous chondrocyte transplantation: a prospective

follow-up at a minimum of 10 years. Am J Sports Med. 2014;42(11):2680–8.
70. Sato M, Ochi M, Uchio Y, Agung M, Baba H. Transplantation of tissue-engineered cartilage for excessive osteochondritis dissecans of the elbow. J Shoulder Elb Surg. 2004;13(2):221–5.
71. Kircher J. Autologous chondrocyte implantation for post-traumatic cartilage defect of the capitulum humeri. J Shoulder Elb Surg. 2016;25(7):e213–e6.
72. Patzer T, Krauspe R, Hufeland M. Arthroscopic autologous chondrocyte transplantation for osteochondritis dissecans of the elbow. Arthrosc Tech. 2016;5(3):e633–e6.
73. Iwasaki N, Yamane S, Nishida K, Masuko T, Funakoshi T, Kamishima T, et al. Transplantation of tissue-engineered cartilage for the treatment of osteochondritis dissecans in the elbow: outcomes over a four-year follow-up in two patients. J Shoulder Elb Surg. 2010;19(8):e1–6.
74. Stone KR, Pelsis JR, Crues JV, Walgenbach AW, Turek TJ. Osteochondral grafting for failed knee osteochondritis dissecans repairs. Knee. 2014;21(6):1145–50.
75. Kiyoshige Y, Takagi M, Yuasa K, Hamasaki M. Closed-wedge osteotomy for osteochondritis dissecans of the capitellum. A 7- to 12-year follow-up. Am J Sports Med. 2000;28(4):534–7.