Osteochondritis dissecans of the humeral capitellum: treatment options and differential indications

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Boston University
OSTEOCHONDRITIS DISSECANS OF THE HUMERAL CAPITELLUM:
TREATMENT OPTIONS AND DIFFERENTIAL INDICATIONS

by

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B.A., Harvard University, 2011

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ACKNOWLEDGMENTS

I thank my readers, Dr. Park and Dr. Offner. I additionally thank Dr. Bae, a former research mentor with whom I completed prior research on this topic.
OSTEOCHONDRITIS DISSECANS OF THE CAPITELLUM: TREATMENT OPTIONS AND DIFFERENTIAL INDICATIONS

WILLIAM P. HENNRIKUS

ABSTRACT

Introduction: Osteochondritis dissecans (OCD) of the capitellum is a focal condition affecting the articular cartilage and subchondral bone, typically in adolescent athletes. Limited data exists regarding the indications and expected outcomes of the various treatment methods of capitellar OCD, and the optimal treatment strategy remains controversial. Risks of progressive capitellar OCD include osteoarthritic changes and permanent elbow disability.

Study Aims: The objective of this literature review is to assess the data and the conclusions to be drawn from the existing literature on the differential indications for the various treatment options for capitellar OCD, using low-level meta-analysis and qualitative observations, to suggest a course of future study with the purpose of clarifying the differential treatment indications and improving the care of capitellar OCD patients. The most recent 10 years (2004-2014) of data are the focus, in order to evaluate the most modern indications, surgical techniques, surgical skills, and clinical outcomes.

Discussion of Published Data: Ultrasound reportedly offers a high predictive value for screening baseball players for capitellar OCD, although sensitivity, specificity, and cost-effectiveness are unknown. Plain radiographs and magnetic resonance imaging (MRI) are useful diagnostic resources for making the decision to operate, but their sensitivities and specificities are imperfect. Evidence suggest that early stage OCD in
physically immature patients may recover with non-operative management, while advanced stage OCD in older patients will likely achieve a better recovery with operative management. Risk factors for poor outcomes following surgical management of capitellar OCD may reportedly include patient age, physical maturity, athletic competition level, large lesion diameter and thickness, and lateral lesion location. The advantages of removal, debridement, and marrow stimulation techniques include the minimal invasiveness associated with arthroscopy. Successful fragment fixation can preserve normal articular properties, but may risk implant complications and secondary surgeries. Mosaicplasty is frequently suggested when patient or lesion characteristics seem to preclude other surgical methods, or when prior surgical treatment attempts fail, but disadvantages of mosaicplasty include the technical complexity of the procedure and the risk of donor site morbidity.

**Conclusions:** The capitellar OCD literature has accumulated a wealth of level IV case series reporting generally satisfactory short-term results of the various surgical options. There is little need for more descriptive literature on this topic at this time. Modern treatment strategies are incomplete and poorly defined, based upon the suggestions of small case series offering disorganized, low-quality data. A study of the cost-effectiveness of ultrasound screening in high-risk athletes would be useful. A large, comparative case-control study or prospective cohort study of higher methodological quality and better standardization is needed to advance the knowledge on this topic, and classification and regression tree analysis could be applied meaningfully. With more
organized data and analysis, it will become easier to take a systematic approach to treating capitellar OCD, settle clinical controversy and improve patient outcomes.
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LIST OF ABBREVIATIONS

AP ............................................................................................................. Anteroposterior
CT ........................................................................................................... Computed Tomography
ICRS ..................................................................................................... International Cartilage Repair Society
MRI .................................................................................................... Magnetic Resonance Image
OCD .................................................................................................... Osteochondritis Dissecans
INTRODUCTION

Definition: Capitellar Osteochondritis Dissecans

Osteochondritis dissecans (OCD) is a focal condition affecting articular cartilage and subchondral bone. OCD most commonly affects the knee, ankle, and elbow joints of adolescent athletes (Edmonds & Polousky, 2013). In the elbow, OCD may occur in the radial head or trochlea, but most commonly involves the capitellum (Jans et al., 2012). The subchondral bone demonstrates softening in early stages of the disease, the overlying articular cartilage fissures in intermediate stages, and in advanced stages, the affected osteocartilagenous lesion may fragment and dissociate, resulting in loose bodies and long-term osteoarthritic joint changes (Bauer et al., 1992). Figure 1 depicts plain radiograph and magnetic resonance images (MRI) of capitellar OCD in anteroposterior (AP) and sagittal views.

Figure 1: Capitellar osteochondritis dissecans. (A) AP plain radiograph, (B) AP MRI, and (C) Sagittal MRI demonstrating capitellar OCD lesions, indicated by black and white arrows, respectively) (Ruchelsman et al., 2010).
Etiology

Though still used to describe this condition, the term “osteochondritis dissecans” has become a supposed misnomer. In 1888, Konig coined the term osteochondritis dissecans to describe the development of intra-articular loose bodies apparently due to spontaneous inflammation without evidence of trauma (König, 2013). While the name has remained, this early hypothesis of inflammation as the cause of osteochondral separation has since been superseded by the popular hypothesis of trauma (Figure 2) (Brand, 2011).

Figure 2. Proposed origin of OCD. Repetitive minor interruptions to the articular tissue successively lead to (A) fracture of the articular cartilage and subchondral bone; (B) complete interruption of the spongy tissue; (C) reparative cartilagenous zone further separating the lesion from its bed; (D) thickening of the reparative zone; and (E) gradual detachment due to mechanical influences within the joint (Brand, 2011).
Most experts currently believe that repetitive microtrauma across the radiocapitellar joint combined with limited vascularity to the developing chondroepiphysis in the adolescent athlete leads to subchondral bone and cartilage failure. A variety of observations contribute to this popular belief.

First, histopathologic studies of OCD lesions have found signs of degenerative cartilage and reparative fibrocartilage tissue without the presence of inflammatory cells, suggesting degenerative and reparative processes induced by repeated stress (Barrie, 1980, 1984; Kusumi et al., 2006).

Second, the condition is most commonly seen in adolescent athletes involved in sports that load the joint with valgus stress via throwing motions (Figure 3) or weight bearing, as in the classic cases of young baseball players and gymnasts, respectively (Nissen, 2014).

![Figure 3. Valgus compressive stress occurs in the elbow during the late cocking and early acceleration phases of the throwing motion (Miller et al., 1995).](image)

The prevalence of OCD has been estimated at 1-2% in little league baseball players (Harada et al., 2006), and 3-4% among middle school and high school baseball
players (Kida et al., 2014). Capitellar OCD has been associated with beginning to play baseball at an earlier age and playing competitively for longer periods of time (Kida et al., 2014).

Additionally, it has been demonstrated that capitellar subchondral bone density is significantly increased in college pitchers as compared to college fielders, suggesting that the capitellum is a focus of stress in the throwing motion (Momma et al., 2011). Furthermore, osteochondral defects of the capitellum have been shown to increase valgus laxity, making the elbow more susceptible to valgus torque and contact forces, and creating a positive feedback that may enhance the damaging effects of repetitive valgus trauma (Mihata et al., 2013).

Third, the capitellum may be relatively hypovascular and prone to ischemia, as it is supplied by trans-epiphyseal end arteries without collateral supply from the metaphysis (Yamaguchi et al., 1997). The limited blood supply may render the capitellar articular surface slow to recover from trauma.

Genetic factors and biomechanical differences in the elbow joint are presently considered secondary factors in the etiology of capitellar OCD, as there have been a number of case reports in the setting of human growth hormone deficiency (Hussain et al., 2011), multiple affected joints (Wünschel & Böhringer, 2012), and both mono- and di-zygotic twins (Kenniston et al., 2008; Pudas et al., 2012; Richie & Sytsma, 2013). There has been an argument for a deficiency in bone remodeling capacity (Crolet et al., 2013), and mutations in collagen and matrix protein genes have been associated with OCD in other joints (Jackson et al., 2010; Stattin et al., 2010).
History and Physical Examination

The onset of OCD symptoms is typically insidious (Kida et al., 2014; Nissen, 2014; Smith et al., 2012). Early OCD may be asymptomatic, and as symptoms arise they will often be self-managed by the athlete like minor strain, symptomatically, with rest and anti-inflammatory medication. The athlete will often play through the pain until episodes of locking/catching occur and the pain sharpens, presenting for medical examination only after the injury has become serious with signs of more advanced cartilage injury such as effusion, loss of extension, and persistent mechanical symptoms (Kida et al., 2014; Nissen, 2014; Smith et al., 2012).

Physical exam evaluates elbow flexion, extension, pronation, and supination; signs of effusion and palpable tenderness; and status of elbow ligaments (Nissen, 2014). Symptoms of capitellar OCD will include a combination of lateral elbow pain, tenderness, swelling, restricted range of motion, elbow instability, and mechanical symptoms such as locking, catching, and crepitus (Bancroft et al., 2013).

Imaging

Ultrasound has been utilized diagnostically in a limited number of screening studies (Harada et al., 2006; Kida et al., 2014). Evidence of OCD on ultrasound includes breaks in the normally continuous echo line and/or a double floor line of the subchondral bone (Figure 4) (Kida et al., 2014).
Figure 4. Diagnostic ultrasound for capitellar osteochondritis dissecans. (A) Procedure for ultrasonic examination of the humeral capitellum with corresponding artistic renderings of the bony anatomy; (B) Ultrasonic images of the humeral capitellum in a healthy elbow, and in an elbow with signs of OCD including a break in the continuity of the echo line and a double floor line of the subchondral bone of the capitellum, indicated by white arrowheads; (C) Diagnostic ultrasound with white arrow and arrowheads indicating OCD, with same elbow plain radiograph, CT scan, and 3-dimensional CT scan correlation; (D) Diagnostic ultrasound with white arrow and arrowheads indicating OCD, with plain radiographs from the same elbow at initial examination, and 2, 6, and 10 months after initial examination, respectively, demonstrating progressive healing of the OCD lesion with elbow rest (Kida et al., 2014).

Use of ultrasound has been reported for screening in the field, however in the clinic, history and physical exam of a patient suspected of suffering from capitellar OCD are typically followed with radiography. Plain radiographic evaluation is conducted in the AP view with the elbow fully extended, and the lateral view with the elbow flexed to 90° (Zbojniewicz & Laor, 2014). Because OCD lesions tend to be located on the anterior aspect of the capitellum, some investigators recommend an additional standard radiographic view: AP with the elbow flexed to 45°, in order to better visualize the anterior aspect and detect smaller lesions (Baker et al., 2010; Takahara et al., 2008). Additional oblique views may be practiced to give a complete picture (Nissen, 2014), and radiographs of the healthy contralateral elbow may be useful for comparison, to help distinguish subtle pathological OCD changes from normal anatomic variants (Smith et
al., 2012). Plain radiographs are commonly classified into three stages according to the visual progression of the OCD lesion (Table 1; Figure 5).

**Table 1. Plain radiographic classification of capitellar osteochondritis dissecans**
(Minami et al., 1979)

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<tr>
<th>Stage</th>
<th>Description</th>
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<tr>
<td>Stage I</td>
<td>Translucent cystic shadow in the lateral or middle capitellum</td>
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<tr>
<td>Stage II</td>
<td>Clear zone or split line between the lesion and subchondral bone</td>
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<tr>
<td>Stage III</td>
<td>Loose body</td>
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Figure 5. Visual examples of the plain radiographic stages of capitellar osteochondritis dissecans. (A) Stage I, radiolucency, circled in white (Kosaka et al., 2013). (B) Stage II, separation, indicated by black arrow; (C) Stage III, empty defect indicated by white arrow and associated osteochondral loose body free within the joint space indicated by black arrowheads (Takahara et al., 2000).

Plain radiographs may have limited sensitivity for assessing the true extent of the osteochondral lesion as they visualize bony architecture only (Kijowski & De Smet, 2005b). Therefore, if plain radiographs display suspicious changes, or if symptoms suggest OCD despite normal plain radiographs, MRI will typically be utilized to visualize
cartilage and soft tissues in addition to bone, differentiate OCD from other elbow pathologies, assess the extent of the OCD lesion, and determine the clinical course of action (Iwasaki et al., 2012; Zbojniewicz & Laor, 2014). MRI is the current standard for imaging assessment of osteochondral lesion size, location, and stability (Bancroft et al., 2013). MRI findings are commonly classified into 4 stages according to the visual progression of the lesion (Table 2; Figure 6). The classification system for capitellar OCD is adopted from that developed for OCD of the knee and Talus (Nelson et al., 1990).

Table 2. **MRI classification of osteochondritis dissecans** (Nelson et al., 1990).

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<tr>
<th>Stage</th>
<th>Description</th>
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<tr>
<td>I</td>
<td>Intact cartilage with subchondral signal change</td>
</tr>
<tr>
<td>II</td>
<td>High-signal breach of overlying cartilage</td>
</tr>
<tr>
<td>III</td>
<td>Thin high-signal rim extending behind the osteochondral fragment</td>
</tr>
<tr>
<td>IV</td>
<td>Mixed- or low-signal loose body</td>
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Figure 6. Visual examples of the MRI stages of capitellar osteochondritis dissecans. (I) Stage I, intact cartilage with signal change, indicated by white arrow; (II) Stage II, high-signal breach of the overlying cartilage, indicated by white arrow; (III) Stage III, high signal rim extending behind the osteochondral fragment, indicated by white arrow (Kijowski & De Smet, 2005a); (IV) Stage IV, mixed- or low-signal loose body, indicated by white arrow (Zbojniewicz & Laor, 2014).

Radiographic findings may also be classified according to OCD lesion location (Figure 7) (Iwasaki et al., 2009; Shi et al., 2012).
Figure 7. Radiographic classification according to osteochondritis dissecans lesion location. (A) Plain radiograph example of a “central,” “contained” lesion, indicated by white arrow; (B) Plain radiograph example of a “lateral” lesion “uncontained” by the lateral margin of the capitellum, indicated by white arrow (Iwasaki et al., 2009). (C) MRI example of a “central,” “contained” lesion; (D) MRI example of a “lateral” lesion “uncontained” by the lateral margin of the capitellum (Shi et al., 2012).

OCD lesions typically present on the anterolateral capitellum, and should not be confused with the anatomic pseudodefect at the posterior junction of the capitellum and the lateral epicondyle (Bancroft et al., 2013) (Figure 8).
Figure 8. Normal capitellar anatomical pseudodefect. A normal anatomical pseudodefect at the posterior junction of the capitellum and the lateral epicondyle, indicated by white arrow, not to be confused with a pathologic osteochondritis dissecans lesion (Rosenberg et al., 2008).

Treatment

The goals of treatment are to restore osteochondral integrity and elbow function, and to avoid degenerative joint disease and irreversible elbow disability. The terms “stable” versus “unstable” in the OCD literature are used to signify an early lesion that is firmly attached to its osseous foundation and may be amenable to conservative management, versus an advanced lesion that is loosely attached or freely dislocated and will likely require operative management, respectively (Jans et al., 2012).

Non-operative Treatment

Conservative management is typically recommended for cases in which history, physical exam, and radiography suggest a stable capitellar OCD lesion (Nissen, 2014). Non-operative treatment consists of a period of rest from elbow activities and related
sports, in order to allow the subchondral bone to heal and reestablish its foundation of support for the overlying cartilage. The period of rest prescribed ranges from 6 weeks to 6 months, depending on the factors such as the extent of the lesion, symptoms, patient preference, and repeat radiographs. Occasionally, if the patient’s habits are recalcitrant to the prescribed activity limitations, a hinged-brace cast, or sling is sometimes used to immobilize the elbow. Elbow immobilization must be managed carefully, however, as the joint can lose functional range of motion relatively quickly. A closely managed course of physical therapy is prescribed, and return to activities is initiated when symptoms have resolved completely, full range of motion has been recovered, and the OCD lesion itself has healed on MRI evaluation (Nissen, 2014).

Operative Treatment

If history, physical exam, and radiographs suggest an unstable lesion, or if a conservative course of rest and activity modifications has failed to improve elbow symptoms and radiographic appearance, surgery is commonly pursued (Nissen, 2014; Smith et al., 2012).

Surgical treatment begins with a thorough examination of range of motion and ligaments under anesthesia, followed by diagnostic arthroscopy (Figure 9) (Nissen, 2014). Arthroscopic approaches to treating elbow OCD have gained popularity as indications, instrumentation, and surgical skills have improved. The minimally invasive technique is now included in the curriculum of subspecialty training, and arthroscopic treatment of OCD is currently attributed an intermediate level of technical difficulty, with technical challenges including the elbow joint’s compartmentalized structure, it’s small
size, and the neurovascular elements to avoid when placing and maneuvering portals (Byram et al., 2013). Advantages of arthroscopic approaches in the elbow include improved joint visualization, better mobility in the small space, decreased infection risk, decreased scarring, and expedited recovery from surgery (Hsu et al., 2009; Takeba et al., 2010).

![Image](image1.png)

**Figure 9. View of diagnostic elbow arthroscopy.** (A) A left elbow undergoing diagnostic arthroscopy; (B) Analogous anatomic illustration (van den Ende et al., 2011).

According to the International Cartilage Repair Society (ICRS), intraoperative findings of OCD are typically classified into four stages according to the level of stability of the osteochondral fragment (*Table 3; Figure 10*) (Brittberg & Winalski, 2003).
Table 3. ICRS *intraoperative* classification of osteochondritis dissecans (Brittberg & Winalski, 2003)

<table>
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<tr>
<th>Stage</th>
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<tr>
<td>Stage I</td>
<td>Stable lesion with continuous but softened area covered by intact cartilage</td>
</tr>
<tr>
<td>Stage II</td>
<td>Lesion with partial discontinuity that is stable when probed</td>
</tr>
<tr>
<td>Stage III</td>
<td>Lesion with a complete discontinuity that has not yet dislocated</td>
</tr>
<tr>
<td>Stage IV</td>
<td>Empty defect with a dislocated fragment or a loose fragment within the lesion bed</td>
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Figure 10. *Intraoperative examples of the classification stages of capitellar osteochondritis dissecans.* (A) Stage I, stable lesion with continuous but softened area covered by intact cartilage; (B) Stage II, lesion with partial discontinuity that is stable when probed; (C) Stage III, lesion with a complete discontinuity that has not yet dislocated; (D) Stage IV, Empty defect with a dislocated fragment or a loose fragment within the lesion bed (Brittberg & Winalski, 2003; Satake et al., 2013).
The therapeutic surgical procedure is planned pre-operatively based upon the clinical impression, but finalized intraoperatively upon direct inspection of the lesion during diagnostic arthroscopy (Kosaka et al., 2013). Following arthroscopic diagnosis, the therapeutic operative course may be performed using a variety of arthroscopic techniques, which fall into four main categories: removal and debridement, marrow stimulation, fixation, and reconstructive mosaicplasty.

**Removal and Debridement**

In this operative course, fibrillations and hypertrophic growth of stable fragments are debrided to near-normal contour in order to reduce the mechanical disruption of the articular surface during elbow movements. Unstable lesions are excised and loose bodies are removed to reduce mechanical disruption within the joint, and the fibrocartilagenous layer over the empty OCD defect is debrided down to a stable base of healthy subchondral bone using a mechanical shaver and/or ring curettes, to further minimize mechanical disruption and attempt to stimulate a healing response of new fibrocartilage to fill in the defect (Nissen, 2014).

**Marrow stimulation**

Marrow stimulation is typically preceded by excision of unstable fragments and removal of loose bodies, and debridement of the lesion bed as described above. Marrow stimulation techniques aim to further stimulate healing in the subchondral bone by drilling the lesion or by performing microfracture (Figure 11).
Figure 11. Marrow stimulation of capitellar osteochondritis dissecans. (A) following fragment excision and debridement of the lesion, a K-wire is aimed perpendicular to the lesion; (B) following drilling with the K-wire, an efflux of marrow elements is observed (Byram et al., 2013). (C) In a separate case following excision and debridement, a 90° angle tip awl is used to perform microfracture (Wulf et al., 2012).

In drilling, a K-wire is used to drill multiple holes into the lesion to induce a release of marrow elements in an attempt to initiate a healing response that will consist of fibrocartilage filling the defect (Byram et al., 2013; Smith et al., 2012). Transchondral drilling may be performed for earlier stage, more stable lesions that do not require excision. In microfracture, a 45° or 90° angle tip awl is used to produce a similar effect (Wulf et al., 2012).
**Fixation**

Fragment fixation may be preceded by debridement and marrow stimulation techniques. Rather than excising the unstable lesion, however, fixation of OCD involves using implants to fix the unstable lesion in place, in an effort to preserve the native hyaline cartilage and normal joint surface properties while marrow stimulation and elbow rest allow the lesion to heal (Hennrikus et al., 2014). It is uncertain whether debridement of the underlying scar tissue down to healthy bone facilitates healing, or if preservation of the existing fibrous attachments that may help supply blood to the fragment is more optimal (Nobuta et al., 2008).

Reported fixation implants vary from soft wires, to metallic nails and pins, to biodegradable pins, to bone peg grafts (Hennrikus et al., 2014; Mihara et al., 2010; Nobuta et al., 2008; Takeba et al., 2010). Although techniques to perform fixation arthroscopically are being actively developed and reported (Figure 12) (Takeba et al., 2010), most surgeons will open the joint when the decision to pursue fragment fixation is made following diagnostic arthroscopy (Hennrikus et al., 2014; Mihara et al., 2010; Nobuta et al., 2008).
Figure 12. **Fixation of capitellar osteochondritis dissecans.** (A) Arthroscopic insertion of bioresorbable pin (small white arrow) through the drill-guide sheath (large white arrow); (B) View of the inserted bioresorbable pin (Takeba et al., 2010).

**Mosaicplasty**

Mosaicplasty is preceded by unstable lesion excision and loose body removal, debridement of the remaining defect, and sometimes accompanied by marrow stimulation techniques. Mosaicplasty involves the use of osteochondral grafts to reconstruct the damaged articular surface, in an attempt to reestablish normal articular contour and stability (Nissen, 2014).

Osteochondral autografts are arthroscopically harvested, typically from the distal aspect of the anterior-lateral femoral condyle or the posterior aspect of the medial femoral condyle (Byram et al., 2013), non-weight bearing areas of the knee where the cartilage depth most nearly matches that of the humeral capitellum, to facilitate bone-to-bone healing (Schub et al., 2013). Less popular sources of osteochondral grafts include the 5th or 6th ribs. Costal hyaline cartilage has similar biomechanical properties to articular cartilage, but matching the contour of the harvested costal graft to the articular
recipient site is reportedly difficult and requires manually shaping the graft with a scalpel (Shimada et al., 2012).

After graft harvesting, the recipient site in the capitellar OCD lesion is drilled with cylindrical holes to accommodate the grafts (Smith et al., 2012), and the harvested plugs are transplanted into the capitellar defect and impacted flush with the neighboring articular surface (Byram et al., 2013). The grafting process may be repeated with multiple plugs until articular integrity is sufficiently restored. The mosaicplasty process is depicted in Figure 13.
Follow-up after surgery is similar to a course of non-operative treatment: a period of rest from elbow activities and related sports, to allow the bone and cartilage to heal, followed by a gradual reintroduction to activities. Depending on the extent of the procedure and surgeon preference, patients may be immobilized for a period of 1-3 weeks (Byram et al., 2013; Kosaka et al., 2013) or begin range of motion exercises the day after surgery (Tis et al., 2012). Gentle resistance and strengthening exercises may be initiated 1-3 months post-operatively, followed by gentle return to sports activity, and full sports activity thereafter (Byram et al., 2013; Kosaka et al., 2013; Maruyama et al., 2014). Return to activities is dictated by clinical and radiographic evaluation, although plain radiographs, MRI, and computed tomography (CT) scans may not completely return to normal for years (Figure 14) (Maruyama et al., 2014; Takeba et al., 2010; Wulf et al., 2012).
Figure 14. Pre-operative versus post-operative radiographs in successful surgical cases of capitellar osteochondritis dissecans. (A) Pre-operative and (B) 2-year post-operative plain radiographs from a patient that was declared radiographically “healed” following mosaicplasty, because capitellar radiolucency and fragmentation resolved and osteophytes and progressive secondary osteoarthritic change were absent, but abnormal localized flattening of the capitellum persisted (Maruyama et al., 2014). (C & D) Pre-operative and (E & F) 7-month post-operative CT scans from a patient that was declared radiographically “healed” following fragment fixation, because union of the fragment was evident, but irregularities of the capitellar surface contour persisted (Takeba et al., 2010). (G) Pre-operative MRI with white arrowheads indicating an empty OCD defect and black arrowheads indicating an osteochondral loose body, and (H) 2-year post-operative MRI from the same patient who was declared radiographically “healed” following mosaicplasty, because thickened cartilage signal had filled in the defect, indicated by white arrowheads (Wulf et al., 2012).
Study Significance

Pediatric elbow injuries are increasing in prevalence as young athletes specialize at earlier ages and train more rigorously year-round for higher levels of competition (Zellner & May, 2013). In youth baseball, for instance, it is estimated that 5% of pitchers suffer serious elbow or shoulder injuries that require surgery or exit from the sport (Fleisig et al., 2011). OCD of the capitellum is one of the most common elbow injuries in youth sports (Zellner & May, 2013), affecting baseball players and gymnasts most often, but also affecting athletes in sports such as volleyball, tennis, golf, wrestling, football, javelin, water polo, and European handball, which similarly load the elbow with repetitive valgus and/or hyperextensive stress (Hariri & Safran, 2010; Rod et al., 2013; Tyrdal & Bahr, 1996). Risks of progressive capitellar OCD include osteoarthritic changes and permanent elbow disability (Bauer et al., 1992; Takahara et al., 2007).

Despite decades of study, the data in the literature on capitellar OCD with which to support surgical decision-making remains weak, and the optimal treatment of capitellar OCD remains controversial (Smith et al., 2012). In an age of increased scrutiny of the value of health care, surgeons are under increasing pressure to gather and share outcomes data of high quality, so that best practices can be streamlined and disseminated, and patient outcomes can be improved (Hennrikus et al., 2012; Kaplan & Porter, 2011).
Study Aims

The objective of this literature review is to assess the data and the conclusions to be drawn from the existing literature on the differential indications for the various treatment options for capitellar OCD, using low-level meta-analysis and qualitative observations, to suggest a course of future study with the purpose of clarifying the differential treatment indications and improving the care of capitellar OCD patients. The most recent 10 years (2004-2014) of data are the focus, in order to evaluate the most modern indications, surgical techniques, surgical skills, and clinical outcomes.
Presentation and Discussion of Published Data

Prevention and Screening

Data

In 2006, Harada et al. screened 153 little league baseball players with sonography and diagnosed OCD in 2 elbows (Harada et al., 2006). Follow-up radiographs and intraoperative findings confirmed the diagnosis.

In 2014, Kida et al. screened 2433 middle school and high school baseball players at training camps with ultrasound, and found distinctive OCD irregularities in 82 athlete elbows (Kida et al., 2014). Follow-up examination was recommended for all with positive findings, and 68 returned for follow-up. OCD was confirmed via plain radiographs in all 68 patients, for a positive predictive value of 100%. OCD lesions of all plain radiograph stages were found. Of the 82 athletes diagnosed, 33% of OCD elbows reported present pain and 82% reported past pain in a survey administered at the time of ultrasound screening. For comparison, of the 2451 elbows with ultrasound findings negative for OCD, 17% reported present pain and 56% reported past pain.

Discussion

OCD is among the most common overuse injuries in youth sports (Stein & Micheli, 2010). Risk factors for injury in youth sports include skeletal immaturity, growth and muscle imbalance, and pressure to compete through pain and fatigue. Prevention begins with proper education and supervision (Stein & Micheli, 2010).
In the case of capitellar OCD, prevention is difficult because patients typically present for medical care with advanced lesions, when they have already become difficult to treat. The symptoms of early lesions tend to be asymptomatic or mild enough that an athlete will play through the pain until the lesion advances and symptoms become severe (Kida et al., 2014; Nissen, 2014).

Ultrasound reportedly offers a 100% positive predictive value for diagnosing capitellar OCD (Kida et al., 2014). Sensitivity and specificity are unknown, however, as only athletes with positive ultrasounds were invited to follow-up and 14 of the 82 athletes with sonographic signs of OCD opted not to follow-up. Nonetheless, ultrasound screening may offer a means to achieve the early diagnosis needed to identify stable lesions and manage them non-operatively before they become complex and expensive surgical problems with uncertain functional outcomes. Ultrasound offers the additional advantage of avoiding the radiation exposure associated with standard radiographs. Once cumbersome machines that occupied entire rooms, musculoskeletal ultrasounds are now high resolution imaging devices the size of laptops. Musculoskeletal ultrasound enjoys wide use and applicability in the United Kingdom, but not so in the United States, where MRI is a more dominant imaging technique. Some suspect that the lucrative reimbursement rates for MRI in the United States versus the low reimbursement for ultrasound is a significant factor contributing to this discrepancy (McNally, 2011).
Radiographic Indicators

Data

In 2005, Kijowski et al. studied the ability of plain radiographs to identify capitellar OCD (Kijowski & De Smet, 2005b). The study group consisted of 15 patients diagnosed with OCD via MRI, of whom 9 underwent surgery and OCD was intraoperatively confirmed, with 7 having surgically confirmed loose bodies. The medical records of the patients were reviewed to assess whether the treating clinicians and radiologists had identified OCD and loose bodies at the time of the initial pre-operative plain radiograph assessment. The pre-operative radiographs were additionally reviewed by the authors retrospectively to determine whether capitellar OCD and loose bodies could be identified retrospectively by those with knowledge of the ultimate MRI and intraoperative diagnosis of OCD. The results of their study are summarized in Table 4.

Table 4. Sensitivity of plain radiographs for diagnosis of capitellar osteochondritis dissecans and loose bodies (Kijowski & De Smet, 2005b).

<table>
<thead>
<tr>
<th></th>
<th>Elbows successfully diagnosed at <strong>initial</strong> plain radiograph evaluation</th>
<th>Elbows successfully diagnosed at <strong>retrospective</strong> plain radiograph evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Of 15 Elbows with <strong>OCD</strong> diagnosed on MRI</td>
<td>7 (47% Sensitivity)</td>
<td>10 (67% Sensitivity)</td>
</tr>
<tr>
<td>Of 7 Elbows with <strong>loose bodies</strong> diagnosed intraoperatively</td>
<td>3 (43% Sensitivity)</td>
<td>4 (57% Sensitivity)</td>
</tr>
</tbody>
</table>
In 2013, Satake et al. reported the sensitivities and specificities of plain radiographic criteria for instability in a cohort of 50 capitellar OCD patients who all had pre-operative plain radiographs taken and underwent surgery afterward to confirm the extent of OCD (Table 5) (Satake et al., 2013).

Table 5. Sensitivities and specificities of plain radiographic criteria for identifying instability in capitellar osteochondritis dissecans (Minami et al., 1979; Satake et al., 2013)

<table>
<thead>
<tr>
<th>Plain Radiograph</th>
<th>Sign of Instability</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage II or III (Separating or loose fragment)</td>
<td>35/40 (88%)</td>
<td>3/10 (30%)</td>
<td></td>
</tr>
<tr>
<td>Stage III (Loose fragment)</td>
<td>17/40 (43%)</td>
<td>10/10 (100%)</td>
<td></td>
</tr>
<tr>
<td>Closed capitellar epiphysis</td>
<td>34/40 (85%)</td>
<td>5/10 (50%)</td>
<td></td>
</tr>
<tr>
<td>Closed lateral epicondylar epiphysis</td>
<td>27/40 (68%)</td>
<td>8/10 (80%)</td>
<td></td>
</tr>
</tbody>
</table>

In 1996, De Smet et al. described 4 MRI signs of instability in OCD lesions in the knee and ankle (De Smet et al., 1996). Four recent studies have assessed these signs of instability in the elbow, comparing MRI findings to intraoperative findings of instability (Table 6) (De Smet et al., 1996; Iwasaki et al., 2012; Jans et al., 2012; Satake et al., 2013). It should be noted that these four studies did not use identical definitions of intraoperative “instability.”
Table 6. MRI signs of instability versus intraoperative findings of instability in osteochondritis dissecans lesions of the capitellum. MRI signs of instability from (De Smet et al., 1996). Illustrative images from (Satake et al., 2013).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>T-2 line of high signal intensity at interface of osteochondral lesion and underlying bone</td>
<td>22/37 (59%) Sensitivity 8/10 (80%) Specificity</td>
<td>Not Available</td>
<td>3/8 (38%) Sensitivity 3/3 (100%) Specificity</td>
<td>3/4 (75%) Sensitivity</td>
</tr>
<tr>
<td>Discrete, round area of homogenous high signal intensity beneath lesion (cyst)</td>
<td>Not Available</td>
<td>Not Available</td>
<td>3/8 (38%) Sensitivity 3/3 (100%) Specificity</td>
<td>1/4 (25%) Sensitivity</td>
</tr>
<tr>
<td>Focal defect in the articular surface</td>
<td>17/37 (46%) Sensitivity 8/10 (80%) Specificity</td>
<td>Not Available</td>
<td>3/8 (38%) Sensitivity 3/3 (100%) Specificity</td>
<td>Not Available</td>
</tr>
<tr>
<td>T-2 high signal intensity breach of articular cartilage and subchondral bone plate</td>
<td>13/37 (35%) Sensitivity 8/10 (80%) Specificity</td>
<td>Not Available</td>
<td>1/8 (13%) Sensitivity 3/3 (100%) Specificity</td>
<td>Not Available</td>
</tr>
<tr>
<td>All four combined</td>
<td>31/37 (84%) Sensitivity 7/10 (70%) Specificity</td>
<td>16/18 (89%) Sensitivity 4/9 (44%) Specificity</td>
<td>8/8 (100%) Sensitivity 3/3 (100%) Specificity</td>
<td>4/4 100% Sensitivity</td>
</tr>
</tbody>
</table>
Discussion

After history and physical examination, imaging is the final indication for surgery. While sonography has been used to diagnose the presence of capitellar OCD, radiography is typically used to assess the severity of the OCD lesion for use in planning a clinical course of action. Radiographic classifications focus on the integrity of the subchondral bone and overlying articular cartilage in an effort to distinguish stable from unstable lesions. A stable lesion is firmly attached to its osseous foundation and may be amenable to conservative management. An advanced lesion is loosely attached or freely dislocated and will likely require operative management.

Plain radiographs appear to have limited sensitivity for diagnosing early OCD (Kijowski & De Smet, 2005b), but may have improved ability to detect advanced, unstable lesions with some sensitivity and specificity (Satake et al., 2013). The reported relationship of closed capitellar and lateral epicondylar epiphyses with OCD instability may be confounded by factors such as age and sports competition levels. Older athletes may tend to have closed epiphyses, compete at higher levels, place more stress on the elbow, play through higher levels of pain before seeking medical attention, and tend to present with more advanced lesions.

On MRI, the precise etiology of the T-2 high signal intensity line at the interface of the OCD lesion and its bed is uncertain – it is thought to represent a breach of the articular surface that allows synovial fluid to penetrate granulation tissue beneath the OCD lesion (Smith et al., 2012). When intraoperative “instability” is defined as ICRS stage III (separating) or stage IV (detached), MRI has reasonable sensitivity and
specificity for identifying unstable OCD (Iwasaki et al., 2012; Satake et al., 2013). Unsurprisingly, studies have found much improved MRI sensitivity and specificity for identifying unstable OCD when intraoperative “instability” is defined more expansively as ICRS stage I (continuous but softened area covered by intact cartilage), stage II (cartilage fissuring), stage III (separating), or stage IV (detached) (Jans et al., 2012; Kijowski & De Smet, 2005a). This definition discrepancy may arise because some authors define stability based upon the strength of the OCD lesion’s attachment to its osseous foundation, while others define stability based upon projected outcome with conservative management, which may be subject to personal opinion, and many authors conflate the two definitions.

### Indications for Non-Operative Versus Operative Treatment

#### Data

Several recent studies reported findings regarding the effectiveness of non-operative treatment with respect to plain radiographic stage (Table 7) and capitellar epiphyseal status (Table 8). (Matsuura et al., 2008; Mihara et al., 2009; Takahara et al., 2007).
Table 7. Non-operative treatment outcome versus plain radiographic stage of capitellar osteochondritis dissecans (Matsuura et al., 2008; Mihara et al., 2009; Minami et al., 1979). “Healed” = radiographically healed. F/U = follow-up.

<table>
<thead>
<tr>
<th>Study</th>
<th>Mean F/U (Months)</th>
<th>Plain Radiograph Stage I</th>
<th>Plain Radiograph Stage II or III</th>
<th>Fisher Exact Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mihara et al., 2009</td>
<td>14</td>
<td>25/30 (83%) Healed</td>
<td>1/9 (11%) Healed</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Matsuura et al., 2008</td>
<td>14</td>
<td>76/84 (90%) Healed</td>
<td>9/17 (53%) Healed</td>
<td>P &lt; 0.001</td>
</tr>
</tbody>
</table>

Table 8. Non-operative treatment outcome versus capitellar epiphyseal status of elbows affected with capitellar osteochondritis dissecans. “Healed” = radiographic healing. “Pain Free” = all pain resolved. “Full Sport” = athlete was able to return to full levels of sports activity equivalent to pre-injury levels. F/U = follow-up.

<table>
<thead>
<tr>
<th>Study</th>
<th>Mean F/U (Months)</th>
<th>Open capitellar epiphysis</th>
<th>Closed capitellar epiphysis</th>
<th>Fisher Exact Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mihara et al., 2009</td>
<td>14</td>
<td>16/17 (94%) Healed</td>
<td>11/22 (50%) Healed</td>
<td>P &lt; 0.01</td>
</tr>
<tr>
<td>Takahara et al., 2007</td>
<td>60</td>
<td>7/11 (64%) Healed; 8/11 (73%) Pain Free; 3/11 (27%) Full Sport</td>
<td>1/19 (5%) Healed; 2/19 (11%) Pain Free; 1/19 (5%) Full Sport</td>
<td>P = 0.001; P = 0.001; P = 0.13</td>
</tr>
</tbody>
</table>

Mihara et al. went on to control for plain radiographic stage to better assess the relationship between epiphyseal status and the effectiveness of non-operative treatment (Table 9) (Mihara et al., 2009).
Table 9. Non-operative treatment outcome versus capitellar epiphyseal status in plain radiograph stage I osteochondritis dissecans patients (Mihara et al., 2009; Minami et al., 1979). “Healed” = radiographic healing.

<table>
<thead>
<tr>
<th>Plain Radiograph Stage I</th>
<th>Open capitellar epiphysis</th>
<th>Closed capitellar epiphysis</th>
<th>Fisher Exact Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15/16 (94%) Healed</td>
<td>10/14 (71%) Healed</td>
<td>P = 0.10</td>
</tr>
</tbody>
</table>

In the non-operative cohort of Mihara et al., the mean time to radiographic healing was 4.2 months (range 4-26 months) in patients with open capitellar growth plates and 8.1 months (range 4-26 months) in patients with closed capitellar growth plates (P < 0.01) (Mihara et al., 2009).

Takahara et al. additionally reported significant findings regarding the effectiveness of non-operative treatment versus operative treatment in patients with closed capitellar epiphyses (Table 10) (Takahara et al., 2007).

Table 10. Non-operative versus operative treatment outcome in capitellar osteochondritis dissecans patients with closed capitellar epiphyses (Masatoshi Takahara et al., 2007). a Operative treatment consisted of loose body removal only, fragment fixation, or mosaicplasty. “Healed” = radiographic healing. “Pain Free” = all pain resolved. “Full Sport” = athlete was able to return to full levels of sports activity equivalent to pre-injury levels. F/U = follow-up.

<table>
<thead>
<tr>
<th>Closed capitellar epiphysis</th>
<th>Non-Operative Treatment</th>
<th>Operative Treatmenta</th>
<th>Fisher Exact Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2/22 (9%) Pain Free; 1/22 (5%) Full Sport</td>
<td>27/66 (41%) Pain Free; 30/66 (45%) Full Sport</td>
<td>P &lt; 0.05; P &lt; 0.001</td>
</tr>
</tbody>
</table>
Furthermore, in their large study of 106 capitellar OCD patients treated both non-operatively and operatively, of whom 102 patients had pre-operative radiographs available, Takahara et al. noted an apparent relationship between capitellar epiphyseal status and plain radiographic stage (Table 11). The same study also noted an apparent relationship between plain radiographic lesion stage and patient age, with mean age 12.8 years for stage I lesions, 13.4 years for stage II lesions, and 17.2 years for stage III lesions (Masatoshi Takahara et al., 2007).

Table 11. Association between capitellar epiphyseal status and plain radiograph stage in osteochondritis dissecans patients (Minami et al., 1979; Takahara et al., 2007)

<table>
<thead>
<tr>
<th>Plain Radiograph Stage</th>
<th>Plain Radiograph Stage I</th>
<th>Plain Radiograph Stage II</th>
<th>Plain Radiograph Stage III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Of 17 elbows with open capitellar epiphysis</td>
<td>13 (76%)</td>
<td>4 (24%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Of 85 elbows with closed capitellar epiphysis</td>
<td>8 (9%)</td>
<td>23 (27%)</td>
<td>54 (64%)</td>
</tr>
</tbody>
</table>

Freeman-Halton Extension of Fisher Exact Test

P < 0.0001

Discussion

The data suggests that early OCD lesions, as defined by plain radiographic staging, respond well to conservative treatment, while advanced lesions do not (Matsuura et al., 2008; Mihara et al., 2009). The distinction is imperfect, however, as a minority of
radiographic stage I lesions have been shown to fail conservative treatment, and a minority of radiographic stage II and III lesions have been shown to recover well with conservative treatment. This may reflect the imperfect sensitivity and specificity of plain radiography to identify and classify capitellar OCD lesions accurately (Kijowski & De Smet, 2005b; Satake et al., 2013).

Studies of non-operative treatment also report significant findings with regard to epiphyseal status, concluding that elbows with open capitellar epiphyses exhibit better healing potential than those with closed epiphyses (Mihara et al., 2009; Takahara et al., 2007). Additionally, Takahara et al. reported that patients with closed capitellar epiphyses achieve superior outcomes with operative treatment (Takahara et al., 2007). While a relationship between epiphyseal status and treatment outcomes may exist, there are also likely interaction effects of lesion stage and patient age. Again, older, more physically developed athletes are likely to compete at higher levels, with higher pain tolerance, and present for medical attention with more advanced, unstable lesions. Although it is unclear which factor exerts the dominant effect on healing potential and patient outcomes, evidence suggests that early stage OCD in physically immature patients may recover with non-operative management, while advanced stage OCD in older patients will likely achieve a better recovery with operative management.
Differential Indications for Operative Treatments

Summary data of studies of surgical treatment of capitellar OCD is presented in Tables 12c-12e.¹

Table 12a. Summary data of studies of removal and debridement for capitellar osteochondritis dissecans (Brownlow et al., 2006; Rahusen et al., 2006; Takahara et al., 2007). Patients in this study underwent fragment removal alone, without debridement of the OCD defect.

<table>
<thead>
<tr>
<th>Study</th>
<th>Pts</th>
<th>M</th>
<th>Sport</th>
<th>Y</th>
<th>Pre ROM</th>
<th>Cap Close</th>
<th>SA, T</th>
<th>Lat</th>
<th>IC RS Stage</th>
<th>Rev</th>
<th>Post ROM</th>
<th>Pain Free</th>
<th>Full Sport</th>
<th>Min F/U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brownlow et al. 2006</td>
<td>29</td>
<td>69%</td>
<td>28%</td>
<td>72% o</td>
<td>X</td>
<td>X</td>
<td>X, X</td>
<td>X</td>
<td>3%</td>
<td>135°</td>
<td>41%</td>
<td>69%</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Rahusen et al. 2006</td>
<td>15</td>
<td>40%</td>
<td>20%</td>
<td>80% o</td>
<td>131°</td>
<td>X</td>
<td>X, X</td>
<td>X</td>
<td>0%</td>
<td>137°</td>
<td>67%</td>
<td>80%</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Takahara et al. 2007¹</td>
<td>55</td>
<td>X</td>
<td>X</td>
<td>107°</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>117°</td>
<td>35%</td>
<td>49%</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>59%</td>
<td>25%</td>
<td>75%</td>
<td>112°</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>2%</td>
<td>125°</td>
<td>41%</td>
<td>60%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ Tables 12a-12e. Summary data of studies of surgical treatment for capitellar osteochondritis dissecans. The National Center for Biotechnology Information PubMed/MEDLINE journals archive was queried with the search term “osteochondritis dissecans elbow.” Summary data from all studies from 2004-2014 offering surgical outcomes data according to surgical technique are presented. Data from 4 studies that mixed surgical techniques, for which data could not be separated according to surgical technique, were excluded (Kosaka et al., 2013; Mihara et al., 2010; Shi, Bae, Kocher, Micheli, & Waters, 2012; Masatoshi Takahara, Mura, Sasaki, Harada, & Ogino, 2007). Pts = number of patients. M = percentage of male patients. Sport = percentage that played baseball (b), gymnastics (g), or other (o). Y = mean patient age at time of surgery, in years. Pre ROM = mean sagittal arc of elbow motion at pre-operative physical exam. Cap Close = percentage of patients with closed capitellar epiphyses. SA, T = OCD lesion surface area in millimeters squared, and OCD lesion thickness in millimeters. Lat = percentage of OCD lesions that breach the lateral margin of the capitellum, as opposed to central lesions that do not. ICRS Stage = International Cartilage Repair Stage (Brittberg & Winalski, 2003). Rev = percentage of patients who, after the initial operation, underwent later revision surgery. Post ROM = mean sagittal arc of elbow motion at follow-up physical exam. Pain Free = percentage of patients for whom all pain resolved by follow-up. Full Sport = percentage of athletes who were able to return to full levels of sports activity equivalent to pre-injury levels, at follow-up. Min F/U = the minimum follow-up for patients included in the study. Mean = the mean values of the data, accounting for the different number of patients in each study, and excluding missing data. X = data not available – missing data was excluded from “mean” calculations.
Table 12b. Summary data of studies of marrow stimulation for capitellar osteochondritis dissecans (Bojanić et al., 2006, 2012 Jones et al., 2010; Miyake & Masatomi, 2011; Schoch & Wolf, 2010; Tis et al., 2012; Wulf et al., 2012). a Marrow stimulation performed via microfracture. b Marrow stimulation performed via drilling.

<table>
<thead>
<tr>
<th>Study</th>
<th>Pts</th>
<th>M</th>
<th>Sport</th>
<th>Y</th>
<th>Pre ROM</th>
<th>Cap Close</th>
<th>SAT</th>
<th>Lat</th>
<th>ICRS Stage</th>
<th>Rev</th>
<th>Post ROM</th>
<th>Pain Free</th>
<th>Full Sport</th>
<th>Min F/U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bojanic et al. 2006a</td>
<td>3</td>
<td>33%</td>
<td>100% g</td>
<td>14</td>
<td>113°</td>
<td>X</td>
<td>143,</td>
<td>X</td>
<td>100% IV</td>
<td>0%</td>
<td>135°</td>
<td>100%</td>
<td>100%</td>
<td>14</td>
</tr>
<tr>
<td>Jones et al. 2010b</td>
<td>25</td>
<td>56%</td>
<td>44% b</td>
<td>13</td>
<td>109°</td>
<td>X</td>
<td>X,  X</td>
<td>X</td>
<td></td>
<td>0%</td>
<td>136°</td>
<td>84%</td>
<td>72%</td>
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</tr>
<tr>
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<td>62% b</td>
<td>16</td>
<td>X</td>
<td>X</td>
<td>138,</td>
<td>X</td>
<td></td>
<td>0%</td>
<td>X</td>
<td>X</td>
<td>31%</td>
<td>12</td>
</tr>
<tr>
<td>Miyake et al 2011b</td>
<td>106</td>
<td>99%</td>
<td>96% b</td>
<td>15</td>
<td>125°</td>
<td>100%</td>
<td>X,  X</td>
<td>X</td>
<td></td>
<td>0%</td>
<td>130°</td>
<td>84%</td>
<td>85%</td>
<td>8</td>
</tr>
<tr>
<td>Bojanic et al. 2012a</td>
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<td>44% g</td>
<td>15</td>
<td>X</td>
<td>67%</td>
<td>X,  X</td>
<td>X</td>
<td></td>
<td>0%</td>
<td>X</td>
<td>X</td>
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<td>24</td>
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<tr>
<td>Tis et al. 2012b</td>
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<td>46% b</td>
<td>13</td>
<td>110°</td>
<td>X</td>
<td>X,  X</td>
<td>X</td>
<td></td>
<td>23%</td>
<td>127°</td>
<td>X</td>
<td>54%</td>
<td>2</td>
</tr>
<tr>
<td>Wulf et al. 2012a</td>
<td>10</td>
<td>40%</td>
<td>40% b</td>
<td>14</td>
<td>116°</td>
<td>30%</td>
<td>X,  X</td>
<td>X</td>
<td></td>
<td>0%</td>
<td>139°</td>
<td>X</td>
<td>60%</td>
<td>27</td>
</tr>
<tr>
<td>Mean</td>
<td>82%</td>
<td>73% b</td>
<td>14% g</td>
<td>15</td>
<td>106°</td>
<td>92%</td>
<td>140,</td>
<td>X</td>
<td>6% I</td>
<td>1%</td>
<td>115°</td>
<td>84%</td>
<td>75%</td>
<td></td>
</tr>
</tbody>
</table>
Table 12c. Summary data of studies of fixation for capitellar osteochondritis dissecans (Hennrikus et al., 2014; Nobuta et al., 2008; Takeba et al., 2010). a Fixed with two soft wires. b Fixed with mean of four bioabsorbable implants. c Fixed with mean 2 implants – 21 cases with bioabsorbable implants, 2 cases with k-wires, 3 cases with mixed bioabsorbable and metallic implants.

<table>
<thead>
<tr>
<th>Study</th>
<th>Pts</th>
<th>M</th>
<th>Sport</th>
<th>Y</th>
<th>Pre ROM</th>
<th>Cap Close</th>
<th>SA, T</th>
<th>Lat</th>
<th>ICRS Stage</th>
<th>Rev</th>
<th>Post ROM</th>
<th>Pain Free</th>
<th>Full Sport</th>
<th>Min F/U</th>
</tr>
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<tr>
<td>Nobuta et al. 2008&lt;sup&gt;a&lt;/sup&gt;</td>
<td>28</td>
<td>100%</td>
<td>96% b</td>
<td>4% o</td>
<td>14</td>
<td>115° X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7%</td>
<td>132°</td>
<td>89%</td>
<td>68%</td>
</tr>
<tr>
<td>Takeba et al. 2010&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4</td>
<td>100%</td>
<td>100% b</td>
<td></td>
<td>15</td>
<td>91° 75%</td>
<td>60, 7</td>
<td>X</td>
<td>100% III</td>
<td></td>
<td>X</td>
<td>128°</td>
<td>100%</td>
<td>X</td>
</tr>
<tr>
<td>Hennrikus et al. Press&lt;sup&gt;c&lt;/sup&gt;</td>
<td>26</td>
<td>50%</td>
<td>35% b</td>
<td>38% g</td>
<td>27% o</td>
<td>14 109° 73%</td>
<td>144, 5</td>
<td>54%</td>
<td>38% II 62% III</td>
<td>23%</td>
<td>127°</td>
<td>62%</td>
<td>67%</td>
<td>17</td>
</tr>
<tr>
<td>Mean</td>
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<td>69% b</td>
<td>17% g</td>
<td>14% o</td>
<td>14</td>
<td>111° 73%</td>
<td>138, 7</td>
<td>54%</td>
<td>33% II 67% III</td>
<td>15%</td>
<td>129°</td>
<td>78%</td>
<td>68%</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Fixed with two soft wires. <sup>b</sup> Fixed with mean of four bioabsorbable implants. <sup>c</sup>Fixed with mean 2 implants – 21 cases with bioabsorbable implants, 2 cases with k-wires, 3 cases with mixed bioabsorbable and metallic implants.
Table 12d. Summary data of studies of mosaicplasty for capitellar osteochondritis dissecans (Iwasaki et al., 2009; Maruyama et al., 2014; Ovesen et al., 2011; Shimada et al., 2012; Tsuda et al., 2005; Vogt et al., 2011; Yamamoto et al., 2006).

<table>
<thead>
<tr>
<th>Study</th>
<th>Pts</th>
<th>M</th>
<th>Sport</th>
<th>Y</th>
<th>Pre ROM</th>
<th>Cap Close</th>
<th>SA, T</th>
<th>Lat</th>
<th>ICRS Stage</th>
<th>Rev</th>
<th>Post ROM</th>
<th>Pain Free</th>
<th>Full Sport</th>
<th>Min F/U</th>
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<tbody>
<tr>
<td>Tsuda et al. 2005</td>
<td>3</td>
<td>67%</td>
<td>33% g</td>
<td>67% o</td>
<td>13</td>
<td>130°</td>
<td>X</td>
<td>X</td>
<td>33% III 67% IV</td>
<td>0%</td>
<td>X</td>
<td>X</td>
<td>100%</td>
<td>16</td>
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<tr>
<td>Yamamoto et al. 2006</td>
<td>18</td>
<td>100%</td>
<td>100% b</td>
<td>14</td>
<td>114°</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>50% III 50% IV</td>
<td>6%</td>
<td>126°</td>
<td>X</td>
<td>78%</td>
<td>24</td>
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<tr>
<td>Iwasaki et al. 2009</td>
<td>19</td>
<td>100%</td>
<td>X</td>
<td>14</td>
<td>112° 100%</td>
<td>147, X</td>
<td>47%</td>
<td>37% III 63% IV</td>
<td>0%</td>
<td>128°</td>
<td>95%</td>
<td>89%</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Ovesen et al. 2011</td>
<td>10</td>
<td>40%</td>
<td>100% o</td>
<td>18</td>
<td>128°</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>100% IV</td>
<td>0%</td>
<td>137°</td>
<td>80%</td>
<td>X</td>
<td>10</td>
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<tr>
<td>Vogt et al. 2011</td>
<td>8</td>
<td>50%</td>
<td>13% g</td>
<td>87% o</td>
<td>17</td>
<td>117°</td>
<td>X</td>
<td>X</td>
<td>100% X</td>
<td>X</td>
<td>0%</td>
<td>135°</td>
<td>X</td>
<td>100%</td>
</tr>
<tr>
<td>Shimada et al. 2012</td>
<td>26</td>
<td>X</td>
<td>X</td>
<td>16</td>
<td>110°</td>
<td>X</td>
<td>256, X</td>
<td>69%</td>
<td>46% III 54% IV</td>
<td>15%</td>
<td>130°</td>
<td>92%</td>
<td>100%</td>
<td>24</td>
</tr>
<tr>
<td>Maruyama et al. 2014</td>
<td>33</td>
<td>100%</td>
<td>100% b</td>
<td>14</td>
<td>116° 88%</td>
<td>224, X</td>
<td>X</td>
<td>39% III 61% IV</td>
<td>0%</td>
<td>133°</td>
<td>91%</td>
<td>94%</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>88%</td>
<td>71% b</td>
<td>4% g</td>
<td>25% o</td>
<td>15</td>
<td>115°</td>
<td>92%</td>
<td>200, X</td>
<td>60%</td>
<td>39% III 61% IV</td>
<td>3%</td>
<td>128°</td>
<td>91%</td>
<td>93%</td>
</tr>
</tbody>
</table>
Table 12e. Mean summary data of each surgical technique for treatment of capitellar osteochondritis dissecans. Mean summary data consists of the mean values of the data, accounting for the different number of patients in each study, and excluding missing data, as calculated in Tables 11a-11d.

<table>
<thead>
<tr>
<th>Surgical Technique</th>
<th>M</th>
<th>Sport</th>
<th>Y</th>
<th>Pre ROM</th>
<th>Cap Close</th>
<th>SA, T</th>
<th>Lat</th>
<th>ICRS Stage</th>
<th>Rev</th>
<th>Post ROM</th>
<th>Pain Free</th>
<th>Full Sport</th>
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<tr>
<td>Debridement</td>
<td>59%</td>
<td>25% g 75% o</td>
<td>20</td>
<td>112°</td>
<td>X</td>
<td>X, X</td>
<td>X</td>
<td>X</td>
<td>2%</td>
<td>125°</td>
<td>41%</td>
<td>60%</td>
</tr>
<tr>
<td>Marrow Stimulation</td>
<td>82%</td>
<td>73% b 14% g 13% o</td>
<td>15</td>
<td>106°</td>
<td>92%</td>
<td>140, X</td>
<td>X</td>
<td>6% I 17% II 23% III 54% IV</td>
<td>1%</td>
<td>115°</td>
<td>84%</td>
<td>75%</td>
</tr>
<tr>
<td>Fixation</td>
<td>78%</td>
<td>69% b 17% g 14% o</td>
<td>14</td>
<td>111</td>
<td>73%</td>
<td>138, 7</td>
<td>54%</td>
<td>33% II 67% III</td>
<td>15%</td>
<td>129°</td>
<td>78%</td>
<td>68%</td>
</tr>
<tr>
<td>Mosaicplasty</td>
<td>88%</td>
<td>71% b 4% g 25% o</td>
<td>15</td>
<td>115°</td>
<td>92%</td>
<td>200, X</td>
<td>60%</td>
<td>39% III 61% IV</td>
<td>3%</td>
<td>128°</td>
<td>91%</td>
<td>93%</td>
</tr>
</tbody>
</table>
Indications for Removal and Debridement

Data

Table 12a summarizes the data from recent studies of removal and debridement for capitellar OCD.

In a 1992 study of long-term follow-up of mean 23 years of patients with capitellar OCD, Bauer et al. reported that 13/31 (42%) patients who underwent loose body removal had persistent symptoms, and 19/31 (61%) had signs of osteoarthritis identified on plain radiographs (Bauer et al., 1992).

Takahara et al. performed simple lesion excision or loose body removal for 55 OCD lesions and reported clinical outcomes with respect to lesion size (Takahara et al., 2007). They reported that 11/21 (52%) “small” lesions occupying < 50% of the capitellar surface radiographically healed at follow-up, versus 1/24 (4%) healing of “large” lesions occupying > 50% of the capitellar surface (P < 0.001).

Discussion

Recent studies of removal and debridement generally report positive results with regard to range of motion, pain, and return to sports (Table 12a), and conclude that the technique is a safe and effective management option for capitellar OCD. These studies are, however, limited in scope, follow-up, and sample size, and largely lack the power to provide meaningful statistical analyses. The rate of long-term osteoarthritic changes is concerning (Bauer et al., 1992), and other surgical techniques may yield superior results.
(Table 12e), particularly for larger lesions (Takahara et al., 2007). It is unreported whether rigorous debridement of the OCD lesion bed following fragment excision or loose body removal improves the post-operative prognosis.

To summarize, large lesion size may reportedly risk poor outcomes following removal and debridement techniques. Perceived advantages of this method include the minimal invasiveness of arthroscopy.

**Indications for Marrow Stimulation**

**Data**

At a follow-up of more than 2 years, Mihara et al. reported that 3 of 4 patients who underwent fragment excision and drilling had recurrent OCD or degenerative changes, including insufficient remodeling of the lateral capitellar margin (Figure 15), with elbow range of motion deficits worse than those of the pre-operative exam (Mihara et al., 2010). The same 3 patients also exhibited enlargement of the radial head.

Similarly, Miyake et al. observed radial head enlargement in 6/12 (50%) patients with open radial head epiphyses versus 1/94 (1%) patients with closed radial head epiphyses (P < 0.0001) (Miyake & Masatomi, 2011). Furthermore, 3/6 cases of radial head enlargement with open epiphyses exhibited osteoarthritic lesions in the radiohumeral joint, and 2 required resection of radial head.
Figure 15. Insufficient post-operative remodeling of the capitellar lateral margin and degenerative change of the radiohumeral joint in an osteochondritis dissecans patient with an open radial head epiphysis. (A) Pre-operative radiograph demonstrating a separating lesion, indicated by white arrow; (B) 15-month post-fragment removal and marrow stimulation, radiograph demonstrates insufficient remodeling of the lateral capitellar margin; (C) 63-month post-operative radiograph demonstrating degenerative change of the radiohumeral joint (Mihara et al., 2010).

Discussion

Recent studies of marrow stimulation generally report positive results with regard to range of motion, pain, and return to sports (Table 11b), and conclude that the technique is a safe and effective management option for capitellar OCD. Again, however, these studies are typically limited in their power to provide meaningful statistical analyses.

The theoretical advantage of marrow stimulation is that it can be performed via arthroscopy, which is minimally invasive, results in less scarring and inflammation, allows a more rapid return to function for the patient. There are few, if any, theoretical arguments against transchondral drilling for earlier stage, more stable lesions that do not require excision. For excised separating fragments or removed loose body lesions, however, the benefit added by drilling or microfracture versus simple debridement is
unreported, and some authors suggest that alternative treatment techniques should be considered for “large” lesions > 50% of the capitellar diameter (Mihara et al., 2010).

Following fragment removal and marrow stimulation, Mihara et al. and Miyake et al. observed significant radial head complications requiring follow-up surgery in patients with laterally uncontained lesions and open radial head epiphyses (Mihara et al., 2010; Miyake & Masatomi, 2011). They speculated that the radial head may enlarge due to its remaining growth potential in the absence of articular contact at the site of the capitellar OCD defect. They suggest that, for large OCD lesions and/or those that breach the lateral margin of the capitellum, reconstructive procedures should be considered.

To summarize, large lesion size and lateral lesion location may reportedly risk poor outcomes following removal and marrow stimulation techniques. Perceived advantages of this method again include the minimal invasiveness of arthroscopy.

**Indications for Fixation**

**Data**

In their cohort of capitellar OCD patients who underwent fragment fixation, Kosaka et al. reported that 4/8 large, detached stage lesions that breached the lateral capitellar margin failed to recover and required revision surgery consisting of loose body removal and mosaicplasty to reestablish the capitellum’s lateral contour and integrity (Kosaka et al., 2013). Mihara et al. also reported radial head enlargement and revision surgery in 1 patient who failed to recover from revision surgery (Mihara et al., 2010).
In their study of soft wire fixation, Nobuta et al. observed radiographic healing in 16/16 (100%) patients with OCD lesions < 9mm thick, versus 7/12 (58%) patients with OCD lesions > 9mm thick (P < 0.01) (Nobuta et al., 2008).

Hennrikus et al. reported a relationship between post-fixation revision rates, lesion width, and patient age (Hennrikus et al., 2014). Mean lesion width was 11mm in patients that healed following fixation surgery, versus 16mm in patients who required revision (P = 0.03). Mean patient age was 14 years in patients that healed following fixation surgery, versus 16 years in patients who required revision (P = 0.01). The risk factors were displayed categorically in a classification and regression tree for the 22 patients of the cohort with available pre-operative MRI (Figure 16) (Breiman et al., 1984).
Figure 16. Classification and regression tree depicting post-fixation revision surgery rates separated according to OCD lesion width and patient age (Hennrikus et al., 2014).

Hennrikus et al. additionally reported 2 instances of bioabsorbable implant related complications: 1 case of an intra-articular loose body arising from a fractured implant (Figure 17), and one painful loose and protruding implant requiring arthroscopic removal (Hennrikus et al., 2014).
Figure 17. Bioabsorbable implant complication following fixation surgery for capitellar osteochondritis dissecans. (A) Sagittal and (B) coronal MRI images depicting an intra-articular loose body arising from a fractured bioabsorbable implant (arrow) in a patient with a healed OCD lesion 12 months post-internal fixation surgery (Hennrikus et al., 2014).

Discussion

Fragment fixation is a procedure specific to ICRS stage II (fissuring) and ICRS grade III lesions in the literature (Table 12c). Recent studies of fragment fixation generally report positive results with regard to range of motion, pain, and return to sports (Table 12c), and conclude that the technique is a safe and effective management option for capitellar OCD. Once more, however, the published studies are generally limited in their power to provide meaningful statistical analyses.

Revision rates in large, lateral lesions has led a number of authors to surmise that fragment fixation is inadequate for large OCD lesions that breach the lateral margin of the capitellum (Kosaka et al., 2013; Mihara et al., 2010; Shi et al., 2012). Theoretically, successful fixation surgery can provide more normal joint surface properties than other treatment techniques that involve lesion excision or osteochondral transplants. A heavily
compromised foundation of subchondral bone may render fixation tenuous, however, and the osteocartilaginous lesions may fragment and lead to loose bodies and the need for revision surgery, to remove the loose bodies and to reconstruct the lateral capitellar margin via mosaicplasty (Kosaka et al., 2013). Nobuta et al. offer ~9mm in thickness, and Hennrikus et al. offer ~15mm in width as an approximate threshold values at which fixation surgery may begin to fail (Hennrikus et al., 2014; Nobuta et al., 2008). It is possible that if threshold values such as these continue to be determined, the considerable revision rate associated with fragment fixation (Table 15) may be improved. Once again, age may influence the healing potential of OCD lesions, but possible confounding factors and interaction effects of physical development, competition level, lesion stage, etcetera, have not been explored with sufficient statistical power.

Finally, theoretical advantages of bioabsorbable implants include their mechanical rigidity and ability to obtain MRI without concern for metallic artifact. Potential risks, however, include irregular degradation resulting in loose bodies and further joint damage (Hennrikus et al., 2014). Non-absorbable implants typically require a second, planned surgery for implant removal. Post-operative swelling and mechanical symptoms must be monitored carefully when implants are utilized.

To summarize, large lesion dimensions (> ~9mm thick, > ~13 mm wide or >50% of capitellar surface area), lateral lesion location, and patient age (> ~15 years) may reportedly risk poor outcomes following fragment fixation techniques (Table 15). Perceived advantages of this method include the preservation of articular cartilage and
normal joint surface properties. Reported disadvantages include a considerable revision rate, and the risk of implant related complications and secondary surgeries.

Indications for Mosaicplasty

Data

Table 13 details the graft and sports recovery data from recent studies of mosaicplasty for capitellar OCD.

Table 13. Graft and recovery data of mosaicplasty surgeries for capitellar osteochondritis dissecans (Iwasaki et al., 2009; Maruyama et al., 2014; Ovesen et al., 2011; Shimada et al., 2012; Tsuda et al., 2005; Vogt et al., 2011; Yamamoto et al., 2006). “Graft Incorp.” = graft incorporation: disappearance of the graft line on post-operative MRI. “Full Sport” fraction of the cohort that was able to return to full levels of sports activity equivalent to pre-injury levels. X = data not available.

<table>
<thead>
<tr>
<th>Study</th>
<th>Donor Site</th>
<th>Mean (range) Graft Number</th>
<th>Mean (range) Graft Diameter in mm</th>
<th>Mean (range) Graft Depth in mm</th>
<th>Mean months to Graft Incorp.</th>
<th>Months to Gentle Throwing per protocol</th>
<th>Full Sport</th>
<th>Mean (range) months to Full Sport</th>
</tr>
</thead>
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<td>9 (8-10)</td>
<td>10 (10)</td>
<td>X</td>
<td>X</td>
<td>3/3</td>
<td>5 (4-6)</td>
</tr>
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<td>Knee</td>
<td>2 (1-3)</td>
<td>6 (5-9)</td>
<td>10 (10)</td>
<td>3 (X)</td>
<td>3</td>
<td>14/18</td>
<td>6 (X)</td>
</tr>
<tr>
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<td>Knee</td>
<td>3 (2-6)</td>
<td>4 (3-6)</td>
<td>X (10-15)</td>
<td>X (4-12)</td>
<td>6</td>
<td>17/19</td>
<td>X (8-12)</td>
</tr>
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<td>Ovesen et al. 2011</td>
<td>Knee</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Vogt et al. 2011</td>
<td>Knee</td>
<td>1 (1)</td>
<td>10 (9-10)</td>
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<td>X</td>
<td>X</td>
<td>8/8</td>
<td>X</td>
</tr>
<tr>
<td>Shimada et al. 2012</td>
<td>Rib</td>
<td>1 (1)</td>
<td>X</td>
<td>15 (15)</td>
<td>X</td>
<td>X</td>
<td>26/26</td>
<td>6 (X)</td>
</tr>
<tr>
<td>Maruyama et al. 2014</td>
<td>Knee</td>
<td>2 (1-3)</td>
<td>7 (5-9)</td>
<td>14 (9-20)</td>
<td>4 (3-4)</td>
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<td>31/33</td>
<td>7 (6-14)</td>
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</tbody>
</table>
There have been several reports of donor site morbidity associated with mosaicplasty. Vogt et al. reported that 2/8 patients showed minimal signs of osteoarthritis at 11 and 14 years follow-up, and 3/8 complained of mild knee pain at the harvest site at 10 years follow-up (Vogt et al., 2011). Maruyama et al report 1 case of mild pain in the donor knee with exercise at follow-up (Maruyama et al., 2014). In their study of 26 capitellar OCD patients treated with reconstructive mosaicplasty using osteochondral autografts from the 5th or 6th rib, Shimada et al reported 1 complication of post-operative pneumothorax, due to damage cause to the costal pleura during harvesting (Shimada et al., 2012). The complication resolved in 1 day with an inserted chest tube.

**Discussion**

Mosaicplasty has become a popular technique reported in the literature (Table 12d), and evidence suggests that it may yield outcomes superior to those achieved with other surgical techniques (Table 12e). Mosaicplasty is typically suggested when lesion stage, size, or location seem to preclude other surgical options, or when other surgeries fail and require revision. As with the literature regarding other treatment methods for capitellar OCD, however, published studies on mosaicplasty are generally limited in their power to provide meaningful statistical analyses.

Graft size and number may influence graft incorporation, with evidence suggesting that fewer, larger plugs yield earlier graft incorporation and earlier return to activities (Yamamoto et al., 2006). Yamamoto et al. and Maruyama et al. used 1-3 grafts of diameter 5-9mm, and observed graft incorporation in 4 months or less on follow-up radiographs (Iwasaki et al., 2009, 2012; Maruyama et al., 2014; Yamamoto et al., 2006).
Compare these observations to those of Iwasaki et al., who used 2-6 grafts of diameter 3-
6mm, and observed graft incorporation in 0/10 elbows at 3 months, 2/10 elbows at 4
months, and 10/10 elbows at 12 months. Graft details and sports recovery data is far from
complete, however, and while return to sports rates were similar across mosaicplasty
studies, it is unclear whether the reported times to return to activities are dictated more by
patient recovery or surgeon preference reflected in established protocols.

The risk of donor site morbidity is a disadvantage of mosaicplasty
(Maruyama et al., 2014; Shimada et al., 2012; Vogt et al., 2011). Some authors have
suggested allograft as an alternative to autograft, but allograft transplant introduces
its own variables such as donor availability and risk of disease transmission (Smith
et al., 2012).

To summarize, as of yet there are no reported risk factors for poor outcomes
following mosaicplasty. Perceived advantages of this method include sound
reconstruction of capitellar contour and integrity with use of healthy osteochondral
transplants. Reported disadvantages include the technical complexity of the procedure
and the risk of donor site morbidity.
Conclusions

The Current State of the Literature

Risk factors for poor outcomes following surgical management of capitellar osteochondritis dissecans may reportedly include patient age, physical maturity, and athletic competition level; large lesion width and thickness, and lateral lesion location. The advantages of removal, debridement, and marrow stimulation techniques include the minimal invasiveness associated with arthroscopy. Successful fragment fixation can preserve normal articular properties, but may risk implant complications and secondary surgeries. Mosaicplasty is frequently suggested when patient or lesion characteristics seem to preclude other surgical methods, or when prior surgical treatment attempts fail, but disadvantages of mosaicplasty include the complexity of the procedure and the risk of donor site morbidity. As a result of these observations, modern treatment commonly follows a general strategy such as that recommended in Table 14.
Table 14. Classification and Treatment strategy for capitellar osteochondritis dissecans. Adapted from Byram et al. (Byram et al., 2013).

<table>
<thead>
<tr>
<th>Progression</th>
<th>Radiographic Findings</th>
<th>Arthroscopic Findings</th>
<th>Treatment</th>
</tr>
</thead>
</table>
| Early       | -Plain radiograph stage I: translucent cystic shadow in lateral or middle capitellum  
              -MRI stage I: intact cartilage with subchondral signal change | -ICRS stage I: softened area covered by continuous, intact cartilage | -Conservative |
| Advanced    | -Plain radiographs stage I or II: clear zone or split line between lesion and subchondral bone  
              -MRI stage II: high-signal breach of overlying cartilage  
              -or MRI stage III: high-signal rim extending behind the osteochondral fragment | -ICRS stage II: partial discontinuity that is stable when probed  
              -ICRS stage III: complete discontinuity that is not yet dislocated | -Marrow stimulation if lesion is central and “small”  
              -Fixation considered if lesion is “medium” and “thin.”  
              -Mosaicplasty considered if lesion is “large” and “thick,” particularly if it breaches the lateral capitellar margin |
| Free        | -Plain radiograph stage III: loose body  
              -MRI stage IV: loose body | ICRS stage IV: loose body | -Removal and marrow stimulation if defect is “small.”  
              -Removal and mosaicplasty if defect is “medium” to “large.” |
Such a treatment strategy is incomplete and poorly defined, however, and based upon the suggestions of small case series offering disorganized, low-quality data. The capitellar OCD literature has accumulated a wealth of level IV case series reporting generally satisfactory short-term results of the various surgical options, including improvements in range of motion, radiographic healing of the OCD lesion, and majority return to sports at 6 months to 1 year follow-up. Although a few larger studies with slightly more sophisticated designs have reported risk factors for poor surgical outcomes, they have not been adequately powered to assess confounding factors and interaction effects, and they have generally reported outcomes of one surgical option without comparison to other treatment methods. The methodological quality of studies on the surgical treatment of OCD is therefore considered weak, believed useful for clinical suggestions and hypothesis generation for future studies at present, but not supportive of surgical decision making as of yet. The published data is limited with regard to number of patients, follow-up period, control group use, randomization, standardization, and selection bias. It seems that there is little need for more descriptive literature on the topic at this time.

Suggestions for Future Research

Prevention and Screening

Although musculoskeletal ultrasound use is limited in orthopaedics in the United States (McNally, 2011), routine ultrasound screening was recently recommended for developmental dysplasia of the hip in newborns (Committee on Quality Improvement,
Subcommittee on Developmental Dysplasia of the Hip, American Academy of Pediatrics, 2000). Ultrasound screening may prove similarly beneficial for high-risk adolescent upper-extremity athletes, such as high school baseball players and gymnasts. A study of cost-effectiveness would be useful. Costs of ultrasound screening may include those associated with device, technician, and reader. Benefits may include the early identification of OCD (and other elbow overuse injuries) to be treated with conservative management before complex clinical problems with uncertain prognoses arise, which may require extended care, repeat plain radiographs and MRI, and surgery, and risk possible retirement from certain sports and activities and permanent joint disability.

_Differential Treatment Indications_

The literature on the treatment of capitellar OCD is ripe for a progression from descriptive case series and surgical outcomes reports, to comparative case-control studies and prospective cohort studies, in order to hone the differential indications for the various surgeries, and gather data to support improved, evidence-based treatment strategies. Higher quality prospectively collected data, and statistical analysis for risk factors for poor surgical outcomes, are required to advance the current knowledge.

The difficulties of conducting more rigorous studies on capitellar OCD are many, however.

First, Capitellar OCD is a relatively rare condition. The largest tertiary care pediatric orthopaedic and sports medicine centers in the United States may see 10-20 surgical cases of capitellar OCD in a year (Hennrikus et al., 2014). Attempting to
accumulate a large number of patients for a single-center study of adequate power to conduct a meaningful statistical analysis may not be reasonable.

Second, patient characteristics and intraoperative findings are heterogeneous. Primary treatment procedures are similarly heterogeneous, and secondary procedures are often necessary and complicate analysis further.

Third, it is difficult to attain long-term follow-up on adolescent patient populations such as this, as maturing patients often transfer their care to adult physicians or move their place of living altogether.

Finally, there are no existing validated outcome measures specific to elbow OCD, and there has been little consensus on how to gather and report findings.

The objectives of future investigation should therefore be to:

1. Enroll a large number of OCD patients in a prospective case-control study.
2. Collect data on patient variables, treatment variables, and treatment outcomes in a standardized fashion.
3. Define specific criteria for treatment failure. This will likely include both functional and radiographic criteria.
4. Identify risk factors for treatment failure among the patient variables and treatment variables collected.
5. Develop a set of differential indications for the various treatment options for capitellar OCD, and design an improved treatment algorithm based upon the evidence.
Patient characteristics to collect include age, gender, race, height, weight, hand dominance, mechanism of injury; history of prior fractures, joint pathologies, elbow surgeries; and family history of OCD or other joint problems. Level of sports activity must be defined, and may include sport-specific variables such as position played (e.g. pitcher versus fielder in baseball).

Physical exam data to collect include swelling, tenderness, pain level at rest, pain level with daily activities, pain level during sports, elbow and shoulder ranges of motion bilaterally, and mechanical symptoms.

Radiographic data to collect include lesion stage, lesion location, patient skeletal maturity (Diméglio et al., 2005), and radial head stability. In addition to OCD staging systems, long-term osteoarthritic/degenerative joint change stages should also be assessed and collected at regular intervals.

Non-operative treatment variables to collect include any activity restrictions, immobilizations, or physical therapy prescribed, and the duration of each.

Intraoperative variables to collect include lesion stage, lesion dimensions, lesion location, and surgical procedure performed, including extent of debridement, method of microfracture, type of fixation implants, number of implants, harvest site for mosaicplasty, dimensions of grafts, number of grafts, and arthroscopic versus open approach. Minor concomitant lesions should be enumerated and described in the same manner.

Follow-up data to collect include the same sports participation, clinical exam, radiographic, and non-operative treatment data, for pre-operative versus post-operative
comparisons. A patient-reported outcomes measure should also be developed, standardized, validated, and collected at regular follow-up intervals.

With enough data, classification and regression tree analysis (Breiman et al., 1984; Hennrikus et al., 2014) may be conducted for each surgical method to identify risk factors for poor outcomes and their relative importance. Classification and regression trees for each method may be compared, and the differential indications and an overall treatment strategy may be gradually improved as the research continues to follow evolving surgical practices.

With more organized data and analysis, it will become easier to take a systematic approach to treating capitellar OCD, settle clinical controversy, and improve patient outcomes.
REFERENCES


in adolescent athletes. *Journal of Pediatric Orthopedics, 30*(1), 8–13. doi:10.1097/BPO.0b013e3181c3be83


osteochondritis dissecans of the capitellum. *Journal of Pediatric Orthopedics, 33*(7), 719–724. doi:10.1097/BPO.0b013e3182924662


treatment for osteochondritis dissecans of the capitellum. *The American

Biomechanical characteristics of osteochondral defects of the humeral
doi:10.1177/0363546513490652


Minami, M., Nakashita, K., & Ishii, S. (1979). Twenty-five cases of osteochondritis

capitellum for osteochondritis dissecans: radiographic and clinical outcomes.
doi:10.1016/j.jhsa.2011.05.024

Momma, D., Mommma, D., Iwasaki, N., Oizumi, N., Nakatsuchi, H., Funakoshi, T., ...
joint in baseball players assessed by computed tomography
341. doi:10.1177/0363546510383487

dissecans of the talus and knee: prospective comparison of MR and


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EDUCATION

Boston University School of Medicine expected’14 Boston, MA
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STANDARDIZED TEST SCORES

MCAT: Cumulative – 35. P-13, V-10, B-12
SAT: Cumulative – 2310. M-750, V-760, W-800

PUBLICATIONS


PRESENTATIONS


ADDITIONAL ABSTRACTS AND CONFERENCE PAPERS


MEDICAL EXPERIENCE

Boston Children's Hospital  
Research Data Coordinator  
Boston, MA  
June 2011 – August 2013

- Coordinated ~30 clinical studies for 3 orthopaedic hand surgeons.
- Wrote/edited protocols, recruited/examined patients, gathered/analyzed data, wrote/edited manuscripts.
- Directed weekly hand team research meetings, observed clinic & OR.

CURE International, Honduras  
Translator, Clinical Assistant  
San Pedro Sula, Honduras  
August 2010

- Translated patient/physician conversations.
- Observed peds ortho clinic and surgery with American visiting doctors and Honduran doctors.
- Transported patients, inserted IV’s, removed sutures.

Penn State Hershey Medical Center  
Student Observer, Shadow  
Hershey, PA  
January 2010

- Observed scoliosis, oncology, & general peds ortho clinics.
- Observed rounds with an internist. Attended grand rounds and morning report.

COLLEGE ATHLETICS

Harvard Varsity Lightweight Crew  
- Oarsman varsity lightweight boat. All-Ivy League 2nd team honors 2010. Undefeated dual-racing season.
- Trained 2-3 hours/day, 6 days/week - fall, winter, & spring.

Harvard JV/Club Soccer  

OTHER UNDERGRADUATE EXPERIENCE

Harvard Crimson Newspaper  
- Wrote film and art reviews for the arts board.

On Harvard Time  
- Wrote for the undergraduate news-comedy web-television show.

WHRB 95.3 FM – Harvard Radio Broadcasting  
- Interviewed Harvard athletes and operated sports broadcast equipment.

Cambridge Queen’s Head Pub  
- Bartended and cooked at undergraduate/graduate student pub.

OTHER WORK EXPERIENCE

Attention Span Media  
Intern  
Los Angeles, CA  
Summer 2009

- Performed research, creative concept, website/twitter account management, and assisted casting and production for various internet based entertainment/advertising productions including Dorm Life and MaxxIQ.

Warner Brothers Studios  
Intern  
Burbank, CA  
Summer 2009
- Wrote reports of screenplay & book potential to become high grossing action movies for development execs.
- Covered desk and phones. Office tasks and errands.

**McP’s Irish Pub**  
*Busser, Waiter, Barback*  
San Diego, CA  
Summers 2007 & 2008

**San Diego Harbor Excursion**  
*Deckhand on Bay Ferry*  
San Diego, CA  
Summers 2007 & 2008

**Lanco Construction Company**  
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Fresno, CA  
Summer 2006

**OTHER VOLUNTEER EXPERIENCE**

**Special Olympics of Massachusetts Summer Games**  
Boston, MA  
Volunteer. First aid coverage.  
June 2011

**Long Way Home Community Service Project**  
San Juan Comalapa, Guatemala  
Volunteer. Taught English, ran soccer camp for kids, site construction.  
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