

# Isolated Articular Fractures of the Distal Humerus

JACOB M. KIRSCH, MD, JEFFREY N. LAWTON, MD

## DEFINITION

- Both traumatic and idiopathic pathology of the articular aspect of the **distal humerus**
- Articular shear fractures of the **capitellum** and **trochlea**, as well as osteochondral lesions of the **distal humerus**

## Distal Humerus Articular Fractures

- Articular shear fractures of the **distal humerus** involving the **capitellum** and/or **trochlea** are relatively uncommon injuries<sup>1-3</sup>
- Only 5% of all **distal humerus** fractures<sup>4-6</sup>
- Can involve an isolated articular segment or can be part of a more complex **fracture** pattern involving the medial or lateral columns of the **distal humerus**<sup>1-3,7,8</sup>
- High rates of concomitant injury to the radial head and ulnar collateral ligament<sup>1,2,9</sup>

## Osteochondritis Dissecans

- Osteochondritis dissecans (OCD) is an acquired idiopathic pathology resulting in disruption of the subchondral bone and overlying hyaline cartilage
- Associated with repetitive microtrauma secondary to valgus and axial loading of the elbow in young athletes<sup>10-13</sup>
- Most commonly affects the anterolateral aspect of the **capitellum**<sup>11,14,15</sup>

## ANATOMY

- The center of rotation of the **capitellum** is approximately 12 to 15 mm anterior and distal relative to the humeral shaft, resulting in approximately 30° of flexion relative to the humeral shaft.<sup>16</sup>
- The medial aspect of the **capitellum** is distinguished from the **trochlea** by the trochlear groove.
- The blood supply to the **capitellum** and lateral **trochlea** arises posteriorly from the radial collateral artery, middle collateral artery, radial recurrent artery, and the interosseous recurrent artery.<sup>17</sup>

## SURGICAL APPROACHES

### Distal Humerus Articular Fractures

- Lateral approach to the elbow is usually sufficient to address **fractures** limited to the **capitellum** and concomitant radial head fractures if present.
- Alternative approaches may be necessary if the **fracture** involves the posteroinferior aspect of the lateral column, extends into the **trochlea**, or has posterior trochlear impaction.<sup>2,3</sup>
- A posterior skin incision coupled with subsequent full-thickness medial and lateral flaps can be made to get to the medial and lateral aspects of the elbow if needed.

### Osteochondritis Dissecans

- Can be approached through either a posterior or laterally based approach, depending on the size and location of the OCD lesion on the **capitellum**

## PRINCIPLES IMPORTANT TO PROCEDURE

- Anatomic restoration of the articular surface of the **distal humerus** is paramount to provide stability and reduce the incidence of elbow stiffness and arthritis.
- Reconstituting a normal radiocapitellar joint is important for both coronal and longitudinal stability of the elbow.<sup>18</sup>

### Distal Humerus Articular Fractures

- Fractures** are often comminuted with small articular fragments and limited subchondral bone to support fixation.
- Poor functional outcomes and coronal instability can occur with fragment excision.<sup>5,19,20</sup>
- Involvement of the lateral **trochlea** has been associated with higher rates of elbow instability.<sup>21</sup>
- Higher rates of nonunion have been associated with **fractures** extending to the posterior humerus.<sup>9,22</sup>

## Osteochondritis Dissecans

- The acceleration phase of the pitching motion produces substantial valgus force on the elbow, which results in radiocapitellar compression.<sup>23,24</sup>
- Valgus torque significantly increases radiocapitellar joint contact pressures regardless of the presence of an OCD lesion.<sup>25</sup>
- Stable OCD lesions can progress and result in loosening and fragmentation.<sup>26</sup>

## Pathogenesis

### Distal Humerus Articular Fractures

- Commonly result from a low-energy fall with the arm in a semiflexed position.<sup>2,3,7,27,28</sup>
- Elbow extension coupled with axial compression of the radial head and proximal ulna into the **capitellum** and **trochlea** produces a shear fracture pattern.
- Increased elbow flexion in conjunction with posteriorly directed forces from the radial head and proximal ulna into the **capitellum** and **trochlea** results in more comminuted fracture patterns.

### Osteochondritis Dissecans

- Multifactorial process driven by recurring articular compression in a susceptible region with a tenuous or “watershed” vascular supply and suboptimal articular cartilage.<sup>12,24,29,30</sup>
- Lateral **capitellum** has softer articular cartilage compared with that of the radial head, which may increase strain and potential damage to the **capitellum**.<sup>31</sup>
- Repetitive articular compression is believed to be the prevailing factor in OCD formation and progression.<sup>11,29,32-35</sup>

## History/Physical Findings

### Distal Humerus Articular Fractures

- Thorough history and physical examination should elucidate the specific mechanism of injury, assess for concomitant injuries, evaluate the soft-tissue envelope around the elbow while providing initial insight regarding the stability of the elbow.
- Concomitant ipsilateral upper extremity injuries can often be present and may not be initially obvious in the setting of distracting injuries.<sup>2,8</sup>
- Up to 30% of patients also have radial head fractures and up to 40% have lateral ligamentous injuries.<sup>1,2,9</sup>

### Osteochondritis Dissecans

- Often young overhead athletes who initially complain of vague lateral elbow discomfort without specific inciting traumatic event
- Can present with elbow effusions, limited range of motion, progressive pain, and occasionally develop mechanical symptoms

- Critical to examine the involved extremity and compare it with the uninjured extremity as differences in the examination may become more obvious when compared with the uninjured side

## Diagnostic Studies

### Distal Humerus Articular Fractures

- Plain radiographs of the elbow including anteroposterior, lateral, and radiocapitellar views
  - Should also evaluate routinely the wrist, forearm, and humerus for additional pathology.
  - The lateral elbow x-ray is usually sufficient for being able to diagnose the presence of an articular shear fracture of the **distal humerus** (Figure 17.1).
  - Plain radiographs alone have only a 66% sensitivity for detecting additional trochlear involvement<sup>36</sup> and are often insufficient to assess the exact **fracture** pattern and extent of injury.<sup>1,3,27,37</sup>
- Computed tomography (CT) with three-dimension reconstruction is very useful to fully characterize the injury and evaluate for additional injuries to the **distal humerus** that may not be obvious from the plain radiographs.
  - The addition of three-dimensional imaging has been shown to improve the reliability, characterization and occasionally treatment strategy of **distal humerus** fractures.<sup>38,39</sup>

### Osteochondritis Dissecans

- Plain films can be nondiagnostic early in the disease process; however, they may demonstrate a flattened, irregular, and sclerotic lesion (Figure 17.2).
  - <50% of early cases of OCD of the **capitellum** are diagnosed on plain films alone.<sup>40</sup>
  - 45° flexion anteroposterior film may provide better visualization of the **capitellum**.<sup>41</sup>



**FIGURE 17.1** Lateral radiograph of the elbow demonstrating a coronal shear fracture of the **distal humerus**. This particular radiograph depicts the “double arc” sign.

- Magnetic resonance imaging (MRI) allows for an earlier diagnosis and more accurate evaluation of the stability of the lesion and integrity of the chondral surface.<sup>10,12,33</sup>
  - Hyperintense signal surrounding the lesion signal on T2-weighted images is the most significant predictor of an unstable lesion (Figure 17.3).<sup>13,14,42</sup>



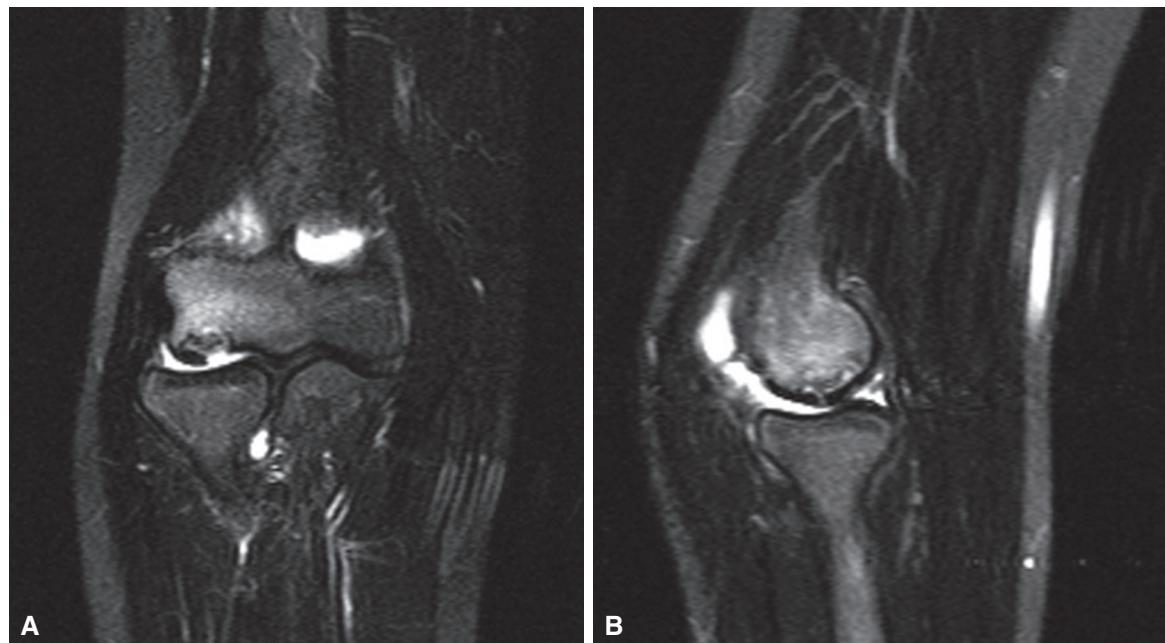
**FIGURE 17.2** Anteroposterior radiograph of the right elbow demonstrating the typical appearance of an osteochondritis dissecans (OCD) lesion of the **capitellum**.

- Jans and colleagues<sup>14</sup> reported 100% sensitivity for determining an unstable OCD lesion on MRI.
- MRI is extremely useful for locating loose bodies in the elbow, which can occur in up to 36% of patients.<sup>14</sup>

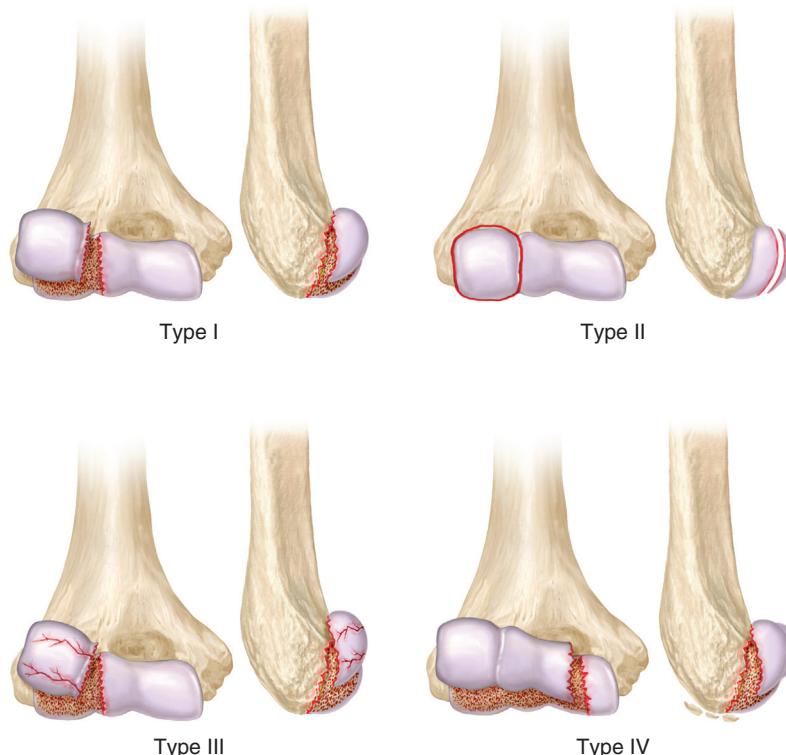
## Diagnosis

### Distal Humerus Articular Fractures

- The diagnosis of distal humeral partial articular fractures is usually based on the clinical history and initial plain radiography of the elbow.
- The most commonly used classification system for these injuries was introduced by Bryan and Morrey<sup>7</sup> and later modified by McKee et al<sup>27</sup> (Figure 17.4).
  - Type I fractures represent a single large capitellar shear fragment, which does not extend medially to involve the **trochlea**.
  - Type II fractures are thin osteochondral fractures, which often involve minimal subchondral bone.
  - Type III fractures are comminuted fractures of the **capitellum**, which frequently can be seen with concomitant injury to the radial head.<sup>43</sup>
  - Type IV fractures extend medially into the **trochlea** as described by McKee et al.<sup>27</sup> Classically, type IV fractures can be identified on the lateral radiograph by the “double arc” sign (Figure 17.1).
- Type I and type IV fracture patterns are the most common (47% and 41%, respectively) followed by type II and type III patterns.<sup>28</sup>



**FIGURE 17.3** Anteroposterior (A) and lateral (B) T2-weighted MRI demonstrating an OCD lesion of the **capitellum**.



**FIGURE 17.4** Classification system for distal humeral articular fractures.

**TABLE 17.1**

**The Minami Classification**

Grade 1	Flattening or cystic changes in the <b>capitellum</b>
Grade 2	Subchondral detachment or fragmentation of lesion
Grade 3	Intra-articular loose body

**Osteochondritis Dissecans**

- The diagnosis of OCD of the **capitellum** is suspected based on the clinical history and confirmed by advanced imaging.
- Often experience vague elbow discomfort, which can progress to more significant pain, limited range of motion, elbow effusion, and occasionally mechanical symptoms resulting from loose bodies.
- Radiographically, the Minami classification is frequently used to characterize OCD lesions on radiographs (Table 17.1).
- Most important classification in directing treatment of these lesions is based on the findings of Takahara et al<sup>26</sup> (Table 17.2).

**Nonoperative Management**

**Distal Humerus Articular Fractures**

- Typically reserved for nondisplaced **fractures** or occasionally for type II osteochondral sleeve fractures

**TABLE 17.2**

**Takahara Classification**

	<b>Capitellar Physis</b>	<b>Range of Motion</b>	<b>Radiographic Changes</b>	<b>Treatment</b>
Unstable	Closed	Restricted >20°	Fragmentation (either displaced or nondisplaced)	Operative intervention
Stable	Open	Normal	Localized flattening or radiolucency	Elbow rest/nonoperative

From Kirsch JM, Thomas JR, Bedi A, Lawton JN. Current concepts: osteochondral autograft transplantation for osteochondritis dissecans of the capitellum. *Hand*. 2016;11(4):396-402.

**Osteochondritis Dissecans**

- Management is primarily based on the stability of the lesion.
- A stable lesion has the potential to heal following a period of rest and limited activity.
  - Patients typically have an open capitellar physis with minimal radiologic changes and relatively normal elbow range of motion.
  - Spontaneous healing in 90% to 94% of patients with an open capitellar physis undergoing nonoperative treatment<sup>35,44</sup>

## SURGICAL MANAGEMENT

### Distal Humerus Articular Fractures

- **Open reduction and internal fixation (ORIF)** of displaced partial articular fractures of the **distal humerus** is the preferred treatment.
- Type II fractures present a unique and challenging scenario because there is often limited, if any, subchondral bone to support fixation. Some authors have advocated using absorbable pins<sup>45</sup> or fibrin glue<sup>46</sup> for these fractures.

### Preoperative Planning

- Partial articular shear fractures of the **distal humerus** require careful preoperative planning.
  - Advanced imaging with 3D reformatted CT is often helpful in determining the extent of the injury and for planning the best surgical approach.
- Lateral approach to the elbow is usually sufficient to address **fractures** limited to the **capitellum** and concomitant radial head fractures if present.
- Large shear fractures with minimal comminution may be amenable to arthroscopic-assisted reduction and fixation.<sup>47-49</sup>

### Positioning/Procedure

- Our preference is to use a lateral approach to the elbow for coronal shear fractures of the **capitellum**. If there is extension to the **trochlea**, then a posterior triceps tongue exposure is employed.
- The patient is placed in the supine position with a hand table extension.
- Prophylactic antibiotics are administered, and the arm is prepped and draped in the usual sterile fashion.
- A sterile tourniquet is placed high in the arm of the operative extremity.
- Lateral incision from the anterior aspect of the lateral column to approximately 2 cm distal to the radial head, centered over the lateral epicondyle.
  - Dissection is carried through the subcutaneous tissues to the fascial layer over the lateral elbow.
  - The lateral supracondylar ridge and radial head can be palpated easily to ensure a correct trajectory is utilized.
  - With the forearm fully pronated, an incision is made sharply down to the bone of the lateral column to elevate the common origin of the radial wrist extensors and the anterior capsule off the lateral supracondylar ridge.
  - Identify and develop the Kaplan interval between the extension carpi radialis brevis and the extensor digitorum communis.
  - Alternatively, one can use the Kocher interval between the extensor carpi ulnaris and the anconeus.

- Flex the elbow and place the retractor deep to the brachialis and anterior capsule and over the medial column to expose the articular surface.
- Avoid retractor placement anterior to the radial neck to decrease possible posterior interosseous nerve injury.
- Extending the elbow helps to facilitate reduction of the articular segment as elbow flexion will often cause limited access to the radial head.
- Provisional fixation of the fragment is accomplished with multiple Kirschner wires to provide rotational stability of the fragment during drilling and screw placement.
- Fluoroscopy is used to verify the reduction, length, and position of the Kirschner wires.
- Cannulated headless compression screws placed from anterior to posterior over the guidewires usually yield sufficient fixation of the fragment, provided there is enough subchondral support (Figure 17.5).
  - Alternatively, fixation can be achieved via screws placed from posterior to anterior; however, headless screws have little biomechanical and economic benefit when performed in this manner.<sup>50,51</sup>
- After final fixation is achieved, range of motion and elbow stability need to be assessed.

The wound is then copiously irrigated and closed in a layered fashion

### PEARLS

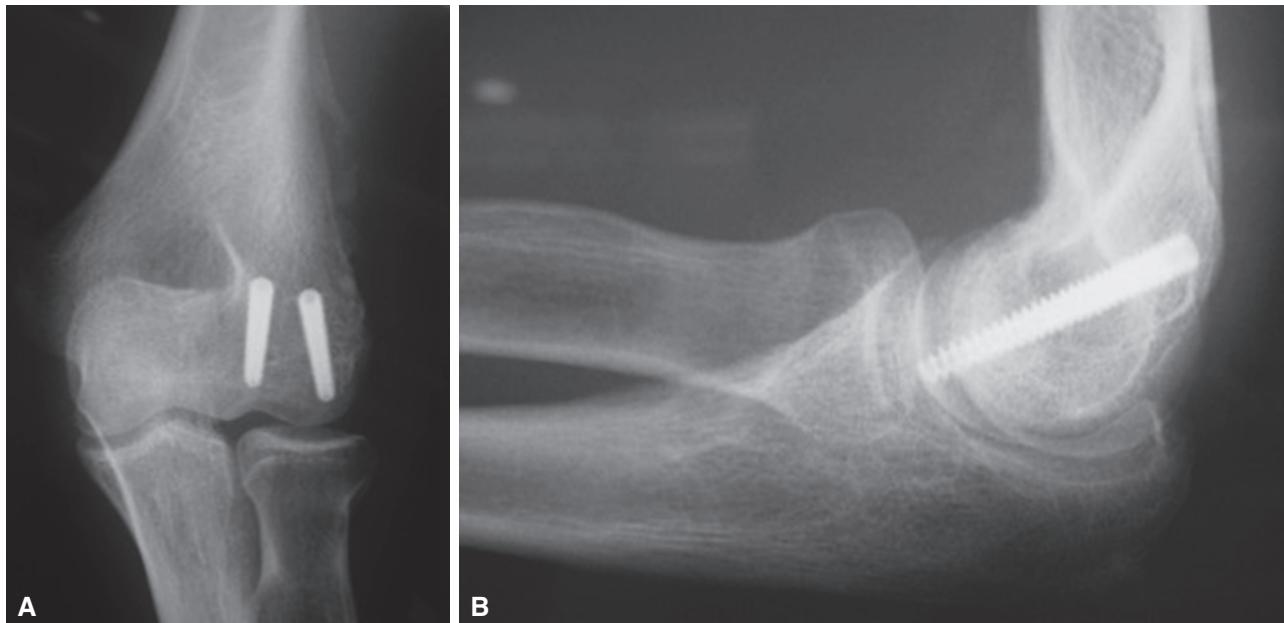
- Thorough preoperative and intraoperative evaluation are critical to assess for concomitant injuries.

### PITFALLS

- Avoid retractor placement anterior to the radial neck to decrease the risk of possible posterior interosseous nerve injury.

## Osteochondral Autograft Transplantation for Capitellar OCD

- Osteochondral autograft transplantation (OAT) involves transplanting a cylindrical portion of nonweight-bearing articular cartilage with the underlying subchondral bone to a different area of the body to fill an osteochondral defect.
- The most common donor sites for the graft are the superolateral aspect of the lateral femoral condyle<sup>10,11,13,15,52,53</sup> and the costal cartilage.<sup>54-56</sup>
- Fibrocartilage formation via microfracture is biomechanically inferior to native hyaline cartilage and fails to provide subchondral bony support.<sup>13,30,57</sup>



**FIGURE 17.5** Anteroposterior (A) and lateral (B) postoperative radiographs after ORIF of a capitellar shear fracture.

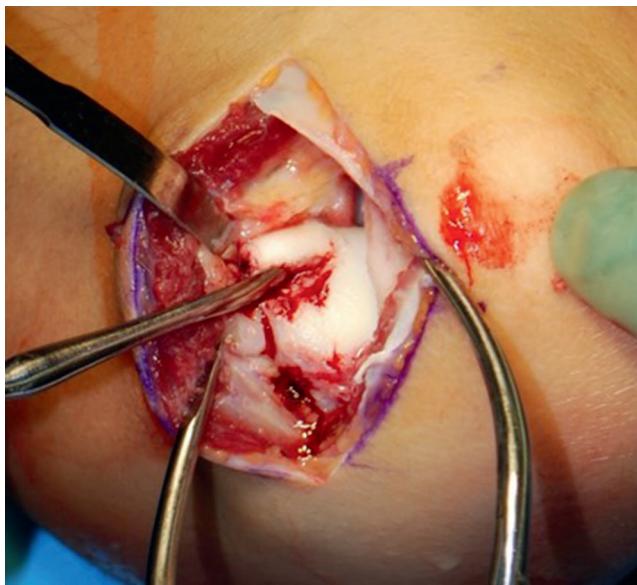
### Preoperative Planning

- Assess possible role of elbow arthroscopy (loose body, chondral fragmentation, lesion amenable to in situ fixation)
- Critical to assess the size and location of the OCD lesion on the **capitellum** to best determine the ideal approach to the elbow to facilitate perpendicular graft placement (posterior vs. lateral)
  - Best done either by preoperative MRI or elbow arthroscopy

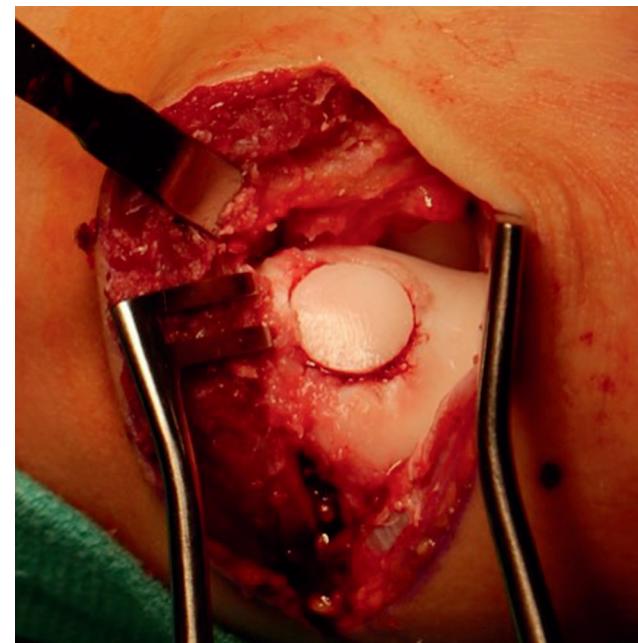
### Positioning/Procedure

- The patient is placed in the supine position on a regular operating table.
- A nonsterile tourniquet is placed high in the arm of the operative extremity and high in the thigh of the ipsilateral leg.
- Both the upper and ipsilateral lower extremity are prepped and draped in the usual sterile fashion.
  - Utilizing a posterior approach to the **capitellum**, a longitudinal incision is made with the elbow hyperflexed, extending approximately 4 cm from just medial to the lateral epicondyle toward the lateral olecranon.
    - Alternatively, for a very anterior lesion, Kaplan's approach is preferred.
  - The incision is carried deep to the subcutaneous tissue until the fascia over the anconeus is encountered.
  - The fascia is split and the anconeus is elevated off the radial surface of the ulna, leaving a periosteal sleeve for later closure and retracted with self-retaining retractors to reveal the underlying joint capsule.

- The capsule is then incised longitudinally, and a self-retaining Gelpi retractor can be placed deep to the capsular layer to facilitate visualization.
- At this point, the OCD lesion of the **capitellum** is directly visualized and critically evaluated (Figure 17.6).
  - It is important to assess the demarcation between normal cartilage and the lesion for accurate sizing of the osteochondral plug.
- A commercially available sizer can then be used to determine the appropriate graft size.
  - We prefer to maximize graft size and minimize the number of plugs that have to be used.
  - Avoid using an unsupported graft if the defect extends to the lateral edge of the **capitellum**.
- Once the appropriate graft size has been determined, the OCD site is then prepared and debrided with a cannulated system of pins and reamers.
- It is imperative that the central pin is positioned perpendicular to the articular surface.
- Following appropriate preparation, attention is then turned to harvesting the osteochondral graft from the knee.
  - A longitudinal lateral parapatellar incision is made and carried deep to the subcutaneous tissue until the knee retinaculum and capsule is encountered.
  - A 3 cm lateral parapatellar arthrotomy is made, being careful to leave a cuff of tissue along the lateral patella to repair at the conclusion of the graft harvest.
  - With the knee in full extension, the patella is gently retracted medially to visualize the nonweight-bearing articular surface of the lateral **trochlea**.



**FIGURE 17.6** An unstable OCD lesion of the **capitellum** as viewed through a posterior approach.



**FIGURE 17.8** The osteochondral plug after it has been impacted into place to fill the OCD lesion.



**FIGURE 17.7** OCD graft harvest from the lateral **trochlea** of the knee. It is critically important to remain perpendicular to the articular surface while harvesting the graft.

- Using the appropriately sized commercially available punch, the graft can then be harvested from the femur.
- It is critical during this step to remain perpendicular to the articular surface (Figure 17.7).
- The osteochondral graft is then impacted into the recipient site in the elbow.

- Overly aggressive graft impaction should be avoided to prevent damage to the articular cartilage and excessive seating of the graft.
- The graft is ideally seated so that it is flushed with the articular surface (Figure 17.8).
- A 15-blade scalpel can be used to trim and contour around the circumference of the graft.
- The elbow is then taken through range of motion testing at the conclusion of the case.
- The elbow and the knee are then copiously irrigated and closed in a layered fashion.

## PEARLS

Maximize graft size and minimize the number of plugs

## PITFALLS

- Avoid using an unsupported graft if the defect extends to the lateral edge of the **capitellum**.
- Avoid leaving the osteochondral graft either too proud or overly recessed to optimize joint contact pressures.

## POSTOPERATIVE MANAGEMENT

### Distal Humerus Articular Fractures

- The patient is immobilized postoperatively in a long arm splint in 90° of flexion with the arm in neutral rotation for approximately 3 to 5 days to allow for early wound healing and comfort.
- The splint is removed and active/active-assisted motion at the elbow is initiated.

- Once full motion is achieved and sufficient **fracture** healing has occurred, strengthening can be initiated by approximately 3 months.

## Osteochondral Autograft Transplantation for Capitellar OCD

- The patient is immobilized postoperatively in a long arm splint in 90° of flexion for approximately 1 week for early wound healing and comfort.
  - The splint is removed and active/active-assisted motion at the elbow is initiated.
  - A knee immobilizer is used for comfort for 2 weeks.
- Strengthening will be delayed until approximately 3 months postoperatively with most athletes returning to sport by approximately 6 months.
- We obtain an MRI to confirm graft incorporation prior to allowing athletes to return to sport.

## Outcomes

### Distal Humerus Articular Fractures

- Most reported series are relatively small and consist of a heterogeneous population with a variety of **fracture** types and limited follow-up.
- Outcomes following ORIF of partial articular shear fractures of the **distal humerus** have generally been encouraging but are highly dependent on the **fracture** pattern.<sup>1-3,9,27,45,58-60</sup>
- Good to excellent functional outcomes as well as post-operative elbow motion have been reported in most series.<sup>1-3,8,27,58,59,61</sup>
- Dubbereley and colleagues<sup>2</sup> reported on 28 patients (11 type I, 4 type II, 13 type III) with a mean age of 43 years and mean follow-up of 56 months.
  - All patients were treated with ORIF.
  - Generally, inferior outcomes were observed when the **fracture** extended to the medial **trochlea** or if the **capitellum** was comminuted.
- Ruchelsman et al<sup>1</sup> reported on 16 patients (6 type I, 2 type III, 8 type IV), with a mean age of 40 years and mean follow-up of 25 months.
  - The authors also reported different functional outcomes depending on the **fracture** pattern, with type IV fracture having significantly decreased elbow motion compared with that of other types.
  - Compared with patients with isolated capitellar fractures, those with radial head fractures had significantly decreased elbow range of motion, lower functional outcome scores, and greater dissatisfaction.<sup>1</sup>
- Guitton et al<sup>8</sup> reported outcomes on a subset of patients with 17-year follow-up.
  - These patients had a median ASES score of 88 points, and a median DASH score of 8 points. Of note, 64% (9/14) had radiographic signs of arthrosis at follow-up.

### Osteochondral Autograft Transplantation for Capitellar OCD

- Recent literature demonstrates encouraging outcomes using OAT for treating osteochondral lesions of the elbow.<sup>10,11,13,15,53-55,62</sup>
- When compared with more conservative management of advanced lesions, OAT has demonstrated more consistent and predictable results.<sup>26,54</sup>
- Mihara and colleagues<sup>54</sup> reported all eligible patients in their series who received OAT were able to return to playing baseball within 4 months.
- Yamamoto et al<sup>13</sup> reported good to excellent outcomes in all patients, with all but two returning to competitive baseball.
- Iwasaki and colleagues<sup>11</sup> reported that 95% of their patients were pain-free at median follow-up of almost 4 years, and 89% of patients were able to return to the same level of competition as they had participated in previously.
- Kirsch et al<sup>63</sup> recently reported that 94% of patients were able to return to competitive sports by a mean of 5.6 months following OAT for capitellar OCD.<sup>63</sup>
- Kosaka and colleagues<sup>64</sup> noted that in “lateral widespread” lesions, inferior outcomes were reported with osteochondral peg fixation compared with that of OAT, with 50% of lateral widespread lesions treated with peg fixation required revision surgery.
  - Conversely, no patients treated with OAT for these laterally extending lesions required revision.<sup>64</sup>

## COMPLICATIONS

### Distal Humerus Articular Fractures

- High rates of reoperation (up to 68%) have been associated with ORIF of partial articular fractures of the **distal humerus**.<sup>2,3,8</sup>
- The most common indication for reoperation following ORIF of partial articular fractures of the **distal humerus** is elbow stiffness.
- On average, flexion contractures of approximately 15° are commonly reported<sup>1,27,59</sup> but usually do not prohibit functional motion.
- Ring et al<sup>3</sup> performed contracture releases in 29% of patients, and Dubberley et al<sup>2</sup> performed contracture releases in 41% of patients following ORIF of partial articular fractures of the **distal humerus**.
- Brouwer et al<sup>22</sup> reported on a series of 30 patients with **fractures** of the **capitellum** and **trochlea**, undergoing operative fixation.
  - The authors reported that patients with comminution of the posterior aspect of the lateral column had significantly higher rates of nonunion compared with other **fracture** patterns.<sup>22</sup>

## Osteochondral Autograft Transplantation for Capitellar OCD

- Residual elbow pain as well as knee pain from the donor site has been reported as an infrequent complication.
- Maruyama and colleagues<sup>65</sup> reported mild elbow pain in only 9% of patients with only one patient having residual knee pain from the donor site.
- Westermann and colleagues<sup>66</sup> reported low rates of overall complications (<5%), with only two cases of donor site morbidity follow graft harvest for OAT.<sup>66</sup>

### SUGGESTED READINGS

- Dubberley JH, Faber KJ, Macdermid JC, Patterson SD, King GJ. Outcome after open reduction and internal fixation of capitellar and trochlear fractures. *J Bone Joint Surg Am.* 2006;88(1):46-54.
- McKee MD, Jupiter JB, Bamberger HB. Coronal shear fractures of the distal end of the humerus. *J Bone Joint Surg Am.* 1996;78(1):49-54.
- Ruchelsman DE, Tejwani NC, Kwon YW, Egol KA. Open reduction and internal fixation of capitellar fractures with headless screws. *J Bone Joint Surg Am.* 2008;90(6):1321-1329.
- Takahara M, Mura N, Sasaki J, Harada M, Ogino T. Classification, treatment, and outcome of osteochondritis dissecans of the humeral capitellum. *J Bone Joint Surg Am.* 2007;89(6):1205-1214.
- Yamamoto Y, Ishibashi Y, Tsuda E, Sato H, Toh S. Osteochondral autograft transplantation for osteochondritis dissecans of the elbow in juvenile baseball players: minimum 2-year follow-up. *Am J Sports Med.* 2006;34(5):714-720.

### REFERENCES

- Ruchelsman DE, Tejwani NC, Kwon YW, Egol KA. Open reduction and internal fixation of capitellar fractures with headless screws. *J Bone Joint Surg Am.* 2008;90(6):1321-1329. doi:10.2106/JBJS.G.00940.
- Dubberley JH, Faber KJ, Macdermid JC, Patterson SD, King GJ. Outcome after open reduction and internal fixation of capitellar and trochlear fractures. *J Bone Joint Surg Am.* 2006;88(1):46-54. doi:10.2106/JBJS.D.02954.
- Ring D, Jupiter JB, Gulotta L. Articular fractures of the distal part of the humerus. *J Bone Joint Surg Am.* 2003;85-A(2):232-238.
- Palvanen M, Kannus P, Parkkari J, et al. The injury mechanisms of osteoporotic upper extremity fractures among older adults: a controlled study of 287 consecutive patients and their 108 controls. *Osteoporos Int.* 2000;11(10):822-831.
- Grantham SA, Norris TR, Bush DC. Isolated fracture of the humeral capitellum. *Clin Orthop Relat Res.* 1981;(161):262-269.
- John H, Rosso R, Neff U, Bodoky A, Regazzoni P, Harder F. Operative treatment of distal humeral fractures in the elderly. *J Bone Joint Surg Br.* 1994;76(5):793-796.
- Ruchelsman DE, Tejwani NC, Kwon YW, Egol KA. Coronal plane partial articular fractures of the distal humerus: current concepts in management. *J Am Acad Orthop Surg.* 2008;16(12):716-728.
- Guitton TG, Doornberg JN, Raaymakers EL, Ring D, Kloen P. Fractures of the capitellum and trochlea. *J Bone Joint Surg Am.* 2009;91(2):390-397. doi:10.2106/JBJS.G.01660.
- Mighell M, Virani NA, Shannon R, Echols EL Jr, Badman BL, Keating CJ. Large coronal shear fractures of the capitellum and trochlea treated with headless compression screws. *J Shoulder Elb Surg.* 2010;19(1):38-45. doi:10.1016/j.jse.2009.05.012.
- Ansah P, Vogt S, Uebelacker P, Martinek V, Woertler K, Imhoff AB. Osteochondral transplantation to treat osteochondral lesions in the elbow. *J Bone Joint Surg Am.* 2007;89(10):2188-2194. doi:10.2106/JBJS.F.00299.
- Iwasaki N, Kato H, Ishikawa J, Masuko T, Funakoshi T, Minami A. Autologous osteochondral mosaicplasty for osteochondritis dissecans of the elbow in teenage athletes. *J Bone Joint Surg Am.* 2009;91(10):2359-2366. doi:10.2106/JBJS.H.01266.
- Ruchelsman DE, Hall MP, Youm T. Osteochondritis dissecans of the capitellum: current concepts. *J Am Acad Orthop Surg.* 2010;18(9):557-567.
- Yamamoto Y, Ishibashi Y, Tsuda E, Sato H, Toh S. Osteochondral autograft transplantation for osteochondritis dissecans of the elbow in juvenile baseball players: minimum 2-year follow-up. *Am J Sports Med.* 2006;34(5):714-720. doi:10.1177/0363546505282620.
- Jans LB, Ditchfield M, Anna G, Jaremko JL, Verstraete KL. MR imaging findings and MR criteria for instability in osteochondritis dissecans of the elbow in children. *Eur J Radiol.* 2012;81(6):1306-1310. doi:10.1016/j.ejrad.2011.01.007.
- 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):140-147.
- London JT. Kinematics of the elbow. *J Bone Joint Surg Am.* 1981;63(4):529-535.
- Yamaguchi K, Sweet FA, Bindra R, Morrey BF, Gelberman RH. The extraosseous and intraosseous arterial anatomy of the adult elbow. *J Bone Joint Surg Am.* 1997;79(11):1653-1662.
- Morrey BF, Tanaka S, An KN. Valgus stability of the elbow. A definition of primary and secondary constraints. *Clin Orthop Relat Res.* 1991;(265):187-195.
- Dushuttle RP, Coyle MP, Zawadsky JP, Bloom H. Fractures of the capitellum. *J Trauma.* 1985;25(4):317-321.
- Mancini GB, Fiacca C, Picuti G. Resection of the radial capitellum. Long-term results. *Ital J Orthop Traumatol.* 1989;15(3):295-302.
- Sabo MT, Fay K, McDonald CP, Ferreira LM, Johnson JA, King GJ. Effect of coronal shear fractures of the distal humerus on elbow kinematics and stability. *J Shoulder Elb Surg.* 2010;19(5):670-680. doi:10.1016/j.jse.2010.02.002.
- Brouwer KM, Jupiter JB, Ring D. Nonunion of operatively treated capitellum and trochlear fractures. *J Hand Surg Am.* 2011;36(5):804-807. doi:10.1016/j.jhsa.2011.01.022.
- Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med.* 1995;23(2):233-239.
- Kobayashi K, Burton KJ, Rodner C, Smith B, Caputo AE. Lateral compression injuries in the pediatric elbow: panner's disease and osteochondritis dissecans of the capitellum. *J Am Acad Orthop Surg.* 2004;12(4):246-254.
- 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):1909-1914. doi:10.1177/0363546513490652.
- Takahara M, Mura N, Sasaki J, Harada M, Ogino T. Classification, treatment, and outcome of osteochondritis dissecans of the humeral capitellum. *J Bone Joint Surg Am.* 2007;89(6):1205-1214. doi:10.2106/JBJS.F.00622.
- McKee MD, Jupiter JB, Bamberger HB. Coronal shear fractures of the distal end of the humerus. *J Bone Joint Surg Am.* 1996;78(1):49-54.
- Watts AC, Morris A, Robinson CM. Fractures of the distal humeral articular surface. *J Bone Joint Surg Br.* 2007;89(4):510-515. doi:10.1302/0301-620X.89B4.18284.
- Kusumi T, Ishibashi Y, Tsuda E, et al. Osteochondritis dissecans of the elbow: histopathological assessment of the articular cartilage and subchondral bone with emphasis on their damage and repair. *Pathol Int.* 2006;56(10):604-612. doi:10.1111/j.1440-1827.2006.02015.x.
- Zlotolow DA, Bae DS. Osteochondral autograft transplantation in the elbow. *J Hand Surg Am.* 2014;39(2):368-372. doi:10.1016/j.jhsa.2013.09.003.
- Schenck RC Jr, Athanasiou KA, Constantinides G, Gomez E. A biomechanical analysis of articular cartilage of the human elbow and a potential relationship to osteochondritis dissecans. *Clin Orthop Relat Res.* 1994;(299):305-312.
- Bradley JP, Petrie RS. Osteochondritis dissecans of the humeral capitellum. Diagnosis and treatment. *Clin Sports Med.* 2001;20(3):565-590.
- 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):1118-1126. doi:10.1007/s11999-012-2290-y.
- Kolmodin J, Saluan P. Osteochondritis dissecans of the humeral capitellum: the significance of lesion location. *Orthop J Sports Med.* 2014;2(4):2325967114530840. doi:10.1177/2325967114530840.
- 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. doi:10.1177/0363546508324970.
- Lee JJ, Lawton JN. Coronal shear fractures of the distal humerus. *J Hand Surg Am.* 2012;37(11):2412-2417. doi:10.1016/j.jhsa.2012.09.001.
- Goodman HJ, Choueka J. Complex coronal shear fractures of the distal humerus. *Bull Hosp Jt Dis.* 2005;62(3-4):85-89.
- Doornberg J, Lindenhovius A, Kloen P, van Dijk CN, Zurakowski D, Ring D. Two and three-dimensional computed tomography for the classification and management of distal humeral fractures. Evaluation of reliability and diagnostic accuracy. *J Bone Joint Surg Am.* 2006;88(8):1795-1801. doi:10.2106/JBJS.E.00944.
- Jacquot A, Poussange N, Charrissoux JL, et al. Usefulness and reliability of two- and three-dimensional computed tomography in patients older than 65 years with distal humerus fractures. *Orthop Traumatol Surg Res.* 2014;100(3):275-280. doi:10.1016/j.otsr.2014.01.003.

40. Kijowski R, De Smet AA. Radiography of the elbow for evaluation of patients with osteochondritis dissecans of the capitellum. *Skeletal Radiol.* 2005;34(5):266-271. doi:10.1007/s00256-005-0899-6.
41. 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. *J Bone Joint Surg Am.* 1998;80(6):892-897.
42. De Smet AA, Ilahi OA, Graf BK. Reassessment of the MR criteria for stability of osteochondritis dissecans in the knee and ankle. *Skeletal Radiol.* 1996;25(2):159-163.
43. Cheung EV. Fractures of the capitellum. *Hand Clin.* 2007;23(4):481-486, vii. doi:10.1016/j.hcl.2007.08.001.
44. Matsuura T, Kashiwaguchi S, Iwase T, Takeda Y, Yasui N. Conservative treatment for osteochondrosis of the humeral capitellum. *Am J Sports Med.* 2008;36(5):868-872. doi:10.1177/0363546507312168.
45. Mighell MA, Harkins D, Klein D, Schneider S, Frankle M. Technique for internal fixation of capitellum and lateral trochlea fractures. *J Orthop Trauma.* 2006;20(10):699-704. doi:10.1097/01.bot.0000246411.33047.80.
46. Scapinelli R. Treatment of fractures of the humeral capitulum using fibrin sealant. *Arch Orthop Trauma Surg.* 1990;109(4):235-237.
47. Hardy P, Menguy F, Guillot S. Arthroscopic treatment of capitellum fracture of the humerus. *Arthroscopy.* 2002;18(4):422-426.
48. Kuriyama K, Kawanishi Y, Yamamoto K. Arthroscopic-assisted reduction and percutaneous fixation for coronal shear fractures of the distal humerus: report of two cases. *J Hand Surg Am.* 2010;35(9):1506-1509. doi:10.1016/j.jhsa.2010.05.021.
49. Mitani M, Nabeshima Y, Ozaki A, et al. Arthroscopic reduction and percutaneous cannulated screw fixation of a capitellar fracture of the humerus: a case report. *J Shoulder Elb Surg.* 2009;18(2):e6-e9. doi:10.1016/j.jse.2008.07.007.
50. Elkowitz SJ, Kubial EN, Polatsch D, Cooper J, Kummer FJ, Koval KJ. Comparison of two headless screw designs for fixation of capitellum fractures. *Bull Hosp Jt Dis.* 2003;61(3-4):123-126.
51. Elkowitz SJ, Polatsch DB, Egel KA, Kummer FJ, Koval KJ. Capitellum fractures: a biomechanical evaluation of three fixation methods. *J Orthop Trauma.* 2002;16(7):503-506.
52. Ahmad CS, Cohen ZA, Levine WN, Ateshian GA, Mow VC. Biomechanical and topographic considerations for autologous osteochondral grafting in the knee. *Am J Sports Med.* 2001;29(2):201-206. doi:10.1177/03635465010290021401.
53. Vogt S, Siebenlist S, Hensler D, 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):2619-2625. doi:10.1177/0363546511420127.
54. Mihara K, Suzuki K, Makiuchi D, Nishinaka N, Yamaguchi K, Tsutsui H. Surgical treatment for osteochondritis dissecans of the humeral capitellum. *J Shoulder Elb Surg.* 2010;19(1):31-37. doi:10.1016/j.jse.2009.04.007.
55. 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):1888-1897. doi:10.1016/j.jse.2014.06.047.
56. Oka Y, Ikeda M. Treatment of severe osteochondritis dissecans of the elbow using osteochondral grafts from a rib. *J Bone Joint Surg Br.* 2001;83(5):738-739.
57. Hangody L, Fules P. Autologous osteochondral mosaicplasty for the treatment of full-thickness defects of weight-bearing joints: ten years of experimental and clinical experience. *J Bone Joint Surg Am.* 2003;85-A(suppl 2):25-32.
58. Sano S, Rokkaku T, Saito S, Tokunaga S, Abe Y, Moriya H. Herbert screw fixation of capitellar fractures. *J Shoulder Elb Surg.* 2005;14(3):307-311. doi:10.1016/j.jse.2004.09.005.
59. Imatani J, Morito Y, Hashizume H, Inoue H. Internal fixation for coronal shear fracture of the distal end of the humerus by the anterolateral approach. *J Shoulder Elb Surg.* 2001;10(6):554-556. doi:10.1067/mse.2001.118005.
60. Singh AP, Singh AP, Vaishya R, Jain A, Gulati D. Fractures of capitellum: a review of 14 cases treated by open reduction and internal fixation with Herbert screws. *Int Orthop.* 2010;34(6):897-901. doi:10.1007/s00264-009-0896-9.
61. Mahirogullari M, Kiral A, Solakoglu C, Pehlivan O, Akmaz I, Rodop O. Treatment of fractures of the humeral capitellum using herbert screws. *J Hand Surg Br.* 2006;31(3):320-325. doi:10.1016/j.jhsb.2006.02.002.
62. Shimada K, Tanaka H, Matsumoto T, 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. doi:10.2106/JBJS.J.00228.
63. 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):1412-1420 e1. doi:10.1016/j.arthro.2017.01.046.
64. Kosaka M, Nakase J, Takahashi R, et al. Outcomes and failure factors in surgical treatment for osteochondritis dissecans of the capitellum. *J Pediatr Orthop.* 2013;33(7):719-724. doi:10.1097/BPO.0b013e3182924662.
65. 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):2122-2127. doi:10.1177/0363546514538759.
66. Westermann RW, Hancock KJ, Buckwalter JA, Kopp B, Glass N, Wolf BR. Return to sport after operative management of osteochondritis dissecans of the capitellum: a systematic review and meta-analysis. *Orthop J Sports Med.* 2016;4(6):2325967116654651. doi:10.1177/2325967116654651.