Title

Failure of Surgery for Osteochondral Injuries of the Elbow in the Pediatric and Adolescent Population

Journal

Current Reviews in Musculoskeletal Medicine, 13(1)

ISSN

1935-973X

Authors

Chen, Eric
Pandya, Nirav K

Publication Date

2020-02-01

DOI

10.1007/s12178-020-09606-2

Peer reviewed

Current Reviews in Musculoskeletal Medicine (2020) 13:50–57
https://doi.org/10.1007/s12178-020-09606-2

PEDIATRIC ORTHOPEDICS (N PANDYA, SECTION EDITOR)

Failure of Surgery for Osteochondral Injuries of the Elbow in the Pediatric and Adolescent Population

Eric Chen [1] · Nirav K. Pandya [2]

Published online: 16 January 2020

Abstract

Purpose of Review With an increase in single-sport specialization, elbow injuries have become increasingly common in the pediatric and adolescent population. Osteochondritis dissecans (OCD) of the capitellum frequently requires intervention yet can be difficult to treat given high patient activity demands. The purpose of this paper is to review treatment options, understand failure rates, and provide strategies for successful revision surgery.

Recent Findings Patients at high risk for the development of this condition are involved in high-demand upper extremity activity such as baseball or gymnastics. Treatment options include non-operative management, drilling, fixation, loose body removal/microfracture, osteochondral autograft, and osteochondral allograft. Cartilage preservation procedures (i.e., osteochondral autograft) have a significant advantage in terms of clinical and radiographic healing compared with fixation or microfracture.

Summary Capitellar OCD lesions afflict a large number of adolescent athletes today and will likely continue increasing in number from sports-related injuries. It is critical to recognize and treat these lesions in a timely and appropriate fashion to optimize clinical outcomes. When faced with failure of healing, surgeons must critically analyze reasons for failure including post-operative compliance, return to high-demand sporting activity, fixation of non-viable fragments, utilization of microfracture, alignment, and concomitant pathology.

Keywords Osteochondritis dissecans · Elbow osteochondral lesions · Adolescent athletes · Baseball players · Gymnasts · Revision surgery

Introduction

Pediatric and adolescent sports participation continues to be characterized by a shift from recreational, free play–based activities to competitive, structured activity. This trend has been quantified via an increase in single-sport specialization [1]. The connection between sports specialization and increased serious injury risk has been well-established [2••]. This has led to an increase in both upper and lower extremity injury risk in this population [3••]. Agresta et al. found that pitching > 100 innings in 1 year, being aged 9 to 11 years, being a pitcher or catcher, training > 16 h per week, and having a history of elbow pain were significant risk factors for elbow injury among youth players [4••].

Increased recognition and treatment of ligamentous and cartilaginous injury in this patient population has not necessarily correlated with increased surgical success rates. In contrast to the adult population, success rates for surgical intervention in pediatric and adolescent anterior cruciate ligament reconstruction [5] and shoulder stabilization [6] have been much lower. Although the reasons for increased failure rate are likely multi-factorial, return to high-risk, high-demand sporting activity places a strain on the interventions for these various pathologies.

Recent studies in the orthopedic literature have examined the incidence, the epidemiology, and the treatment recommendations for osteochondritis dissecans (OCD) lesions of the

This article is part of the Topical Collection on *Pediatric Orthopedics*

✉ Nirav K. Pandya
Nirav.Pandya@ucsf.edu

Eric Chen
Eric.Chen@dignityhealth.org

[1] San Francisco Orthopedic Residency Program, 450 Stanyan Street, San Francisco, CA 94117, USA

[2] Department of Orthopedic Surgery, Benioff Children's Hospital, University of California San Francisco, 747 52nd Street, Oakland, CA 94609, USA

elbow. OCD of the elbow has been theorized to stem from a variety of causes including inflammation, genetics, and microtrauma [7]. Yet, no definitive cause has been clearly identified. Anatomically, the tenuous vascular supply to the capitellum arises from the radial recurrent and interosseous recurrent arteries, leading to relatively poor healing potential. Repetitive damage to the articular surface ultimately leads to synovial fluid and inflammatory factors being exposed to the subchondral bone, preventing osseous healing. Repetitive activity, which is omnipresent in single-sport specialization culture, has been postulated to be one culprit in the development of these lesions [8•]. It appears that persistent microtrauma seems to be most correlated with its development, as there is a drastic increase in relative risk with overhead and weight-bearing activities of the upper extremities [8•, 9]. As children and adolescents specialize at younger and younger ages into specific sports combined with the year-round schedule that many of these athletes follow, it is critical for orthopedic surgeons to understand the prognosis and treatment plans for these sports-related injuries and how to manage failure of intervention.

Demographics and Epidemiology

In the general population for patients aged 6 to 19 years, the incidence of OCD of the elbow is 2.2 per 100,000 according to Kessler et al. [10••]. Gender has a significant predilection toward males, with an OR of 6.8 times greater as compared with females (3.8 vs. 0.6 per 100,000). In addition, age is related with older patients (12–19 years old) having an incidence of 3.4 per 100,000 compared with patients 6 to 11 years old, 0.38 per 100,000. Non-Hispanic white males have the highest overall incidence at 7.4 per 100,000. The majority of lesions were on the right elbow, which the authors hypothesize is related to right-hand dominance being more common.

In an ultrasonographic and radiographic analysis of competitive baseball players aged 10–12, Matsuura et al. demonstrated an overall prevalence of OCDs of 2.1% with no predilection to position or age [11•]. Kida et al. found a prevalence of 3.4% among junior high school and high school baseball players [8•]. Again, there was no statistically significant correlation with position; however, duration of competitive play and play at early ages did show increased risk for development of OCD of the elbow. In gymnasts, only small case-control studies have been published. Dexel et al. assessed a local team of 30 full-time athletes, with 10 having MRI-proven OCD lesions [12].

The clinical significance of the increasing numbers of OCD lesions of the capitellum was emphasized by Weiss et al. who demonstrated that despite only 12.0% of all OCDs being found in the elbow, these lesions had a significantly higher risk of progressing to surgical intervention at 55.0% [13•]. The global rate for surgery was found to be 35.0% in this study, with knee and ankle osteochondral defects at 33.5% and 31.8% respectively. Although age of the patient was a factor in time to diagnosis, this study supports that it is critical for the orthopedic surgeon to recognize this potential injury in the adolescent athlete to achieve the optimal prognosis.

Treatment Principles and Methods

Recommendations on treatment still remain somewhat controversial. General principles in the management of OCD lesions (including the elbow) are that younger age/greater amount of growth remaining is correlated with an increased rate of healing [14]. In addition, the clinician can choose from the following options: non-operative management, retrograde drilling, internal fixation, loose body removal and microfracture, osteochondral autograft, and osteochondral allograft. We will concentrate on the success and failure rates of surgical intervention.

Retrograde Drilling

There is limited literature examining the outcomes of retrograde drilling of stable lesions of the capitellum (Fig. 1). This can be postulated to be due to the fact that stable lesions are hard to identify (as many patients will continue to participate in high-demand activity even with a stable lesion as the arm is non-weight-bearing) and that many stable lesions will respond to non-operative management. Duquin et al. reported on 5

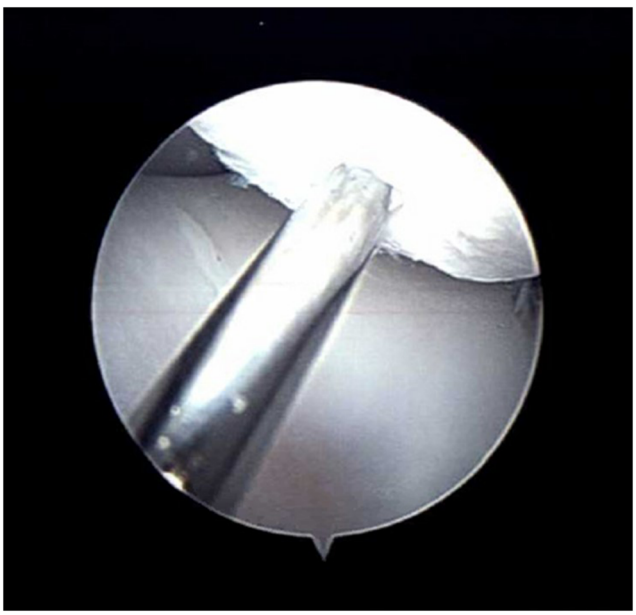

Fig. 1 Arthroscopic imaging demonstrating retrograde drilling of a stable capitellar osteochondral lesion in an adolescent baseball pitcher

elbows with stable capitellar lesions that underwent retrograde drilling, all of which healed [15]. Tis et al. also examined 13 elbows with capitellar osteochondral lesions, of which 7 underwent transhumeral drilling and 2 trans-articular drilling. In their cohort, outcomes were mixed with three patients requiring repeat procedures, and 33% reporting occasional pain [16].

Internal Fixation

Internal fixation of osteochondral lesions, which are unstable but viable, has been shown to have positive outcomes in the literature. Koehler et al. examined an all-arthroscopic suture fixation technique in 5 elite adolescents with unstable OCD lesions of elbow and found 100% union and return to elite athletic level [17]. Similarly, Uchida et al. examined 18 adolescent baseball players with capitellar osteochondral lesions stabilized with absorbable fixation pins, and achieved healing in 17/18 patients with 15 patients returning to the same or higher level of sport [18].

Yet, it is important for surgeons to recognize that size (along with viability) of the lesion is associated with failure of treatment (Fig. 2a–d). Nobuta et al. examined 28 patients with capitellar osteochondral lesions who underwent fixation [19]. Unlike prior studies, they found only 11 patients with complete healing, 12 with partial healing, three with no healing, and two with loose body formation. The authors found that fragment fixation was effective in lesions that were less than 9 mm thick. When lesions were larger than 9 mm, fixation was not indicated. Similarly, Hennrikus et al. examined 26 elbows who underwent internal fixation for unstable osteochondral lesions and found 20/26 patients healed with 2/3 of patients returning fully to sporting activity [20•]. Although the majority of patients had good outcomes, patients less than 15 years of age and with < 13 mm of sagittal width lesions had better outcomes.

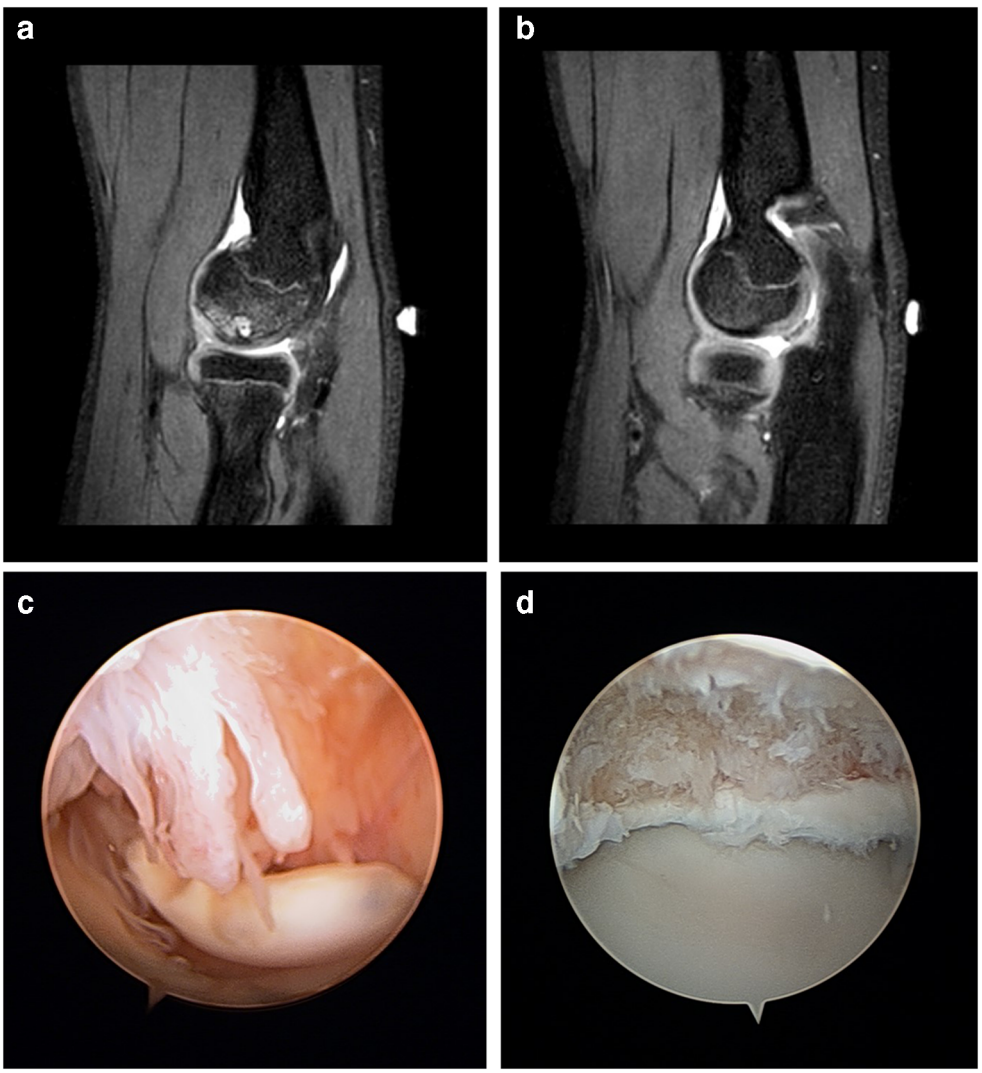

Fig. 2 **a** T2 sagittal MRI image of a 13-year-old male baseball player with an anterior capitellar osteochondral lesion. **b** T2 sagittal MRI image demonstrating a posterior loose body in the same patient. c Non-viable loose body at the time of arthroscopy. d Arthroscopic image of the capitellar osteochondral defect after preparation of the bed prior to cartilage restoration

Loose Body Removal and Microfracture

At the time of arthroscopy, the presence of non-viable loose body (i.e., no attached subchondral bone) or large unstable lesion that cannot be stabilized may be found. For many of these lesions, loose body removal and microfracture have been traditionally performed. Wulf et al. examined 10 adolescent patients who underwent arthroscopy and microfracture with 80% of patients demonstrating reparative fibrocartilage on follow-up MRI with 6/8 patients returning to sport. Yet, the results of this treatment have been mixed in other literature [21] (Fig. 3a, b). Bexkens et al. examined 81 elbows that underwent arthroscopy and microfracture for capitellar lesions, and found that only 62% of patients returned to sporting activity [22••]. Shorter pre-operative duration of symptoms, concurrent loose body removal, and open capitellar physis were associated with more positive outcomes. Lewine et al. examined a cohort of 21 adolescent patients who underwent loose body removal with drilling/microfracture and found similarly mixed results [23••]. Only 71.4% of patients had complete healing and four patients required repeat intervention. Only 66.7% of patients were able to return to their primary sport. As with the study of Bexkens et al., shorter duration of symptoms was associated with smaller osteochondral lesions as well with subsequent higher healing rates and return to sport. In our cohort of 22 pediatric and adolescent athletes, we also found a similar poor return to sport outcome with only 60% of baseball players and 44% of gymnasts able to return to the same level of sporting activity [24].

Osteochondral Grafting

Due to the high activity demands of these patients with relatively guarded outcomes with loose body removal and microfracture, restoration of the articular cartilage in a definitive fashion may be the preferred option to maximize function and prevent treatment failure in this population. Bae et al. examined 28 adolescent patients with unstable capitellar osteochondral lesions who underwent single-plug OATS [25••]. On post-operative MRI, 86% of patients had restoration of articular congruity and 93% had complete graft incorporation. In their cohort of patients with greater than 6-month follow-up, 69% returned to primary sport and 100% had returned to general sports. Further, Lyons et al. examined 11 adolescent patients with large (> 1 cm^2) OCD lesions who were treated with an osteochondral autograft plug [26••]. All patients involved in competitive high school sports returned to play at an average of 4.4 months with a significant improvement in range of motion. In another group of high-demand athletes, Yamamoto et al. examined 18 adolescent baseball players who underwent an OATS procedure with 14 out of 18 patients returning to their prior sports performance levels [27]. Maruyama also examined another high-demand cohort of 33 pediatric and adolescent baseball players with lesions on their throwing arm who underwent an OATS procedure. At a mean of 6.9 months after surgery, all but 2 patients returned to their prior competitive level of sport with all patients achieving radiographic graft incorporation [28•]. Iwasaki et al. examined 8 adolescent baseball players whose throwing arms had capitellar OCD lesions [29]. All patients had radiographic healing with 6 out of the 8 patients (including 3 patients) returning to competitive-level baseball.s

Osteochondral Allograft

There is limited literature on fresh osteochondral allograft transplantation. Mirzayan et al. examined 9 adolescent baseball players who were treated with this method. All patients return to throwing and were active in their sports with functional improvement and pain reduction [30].

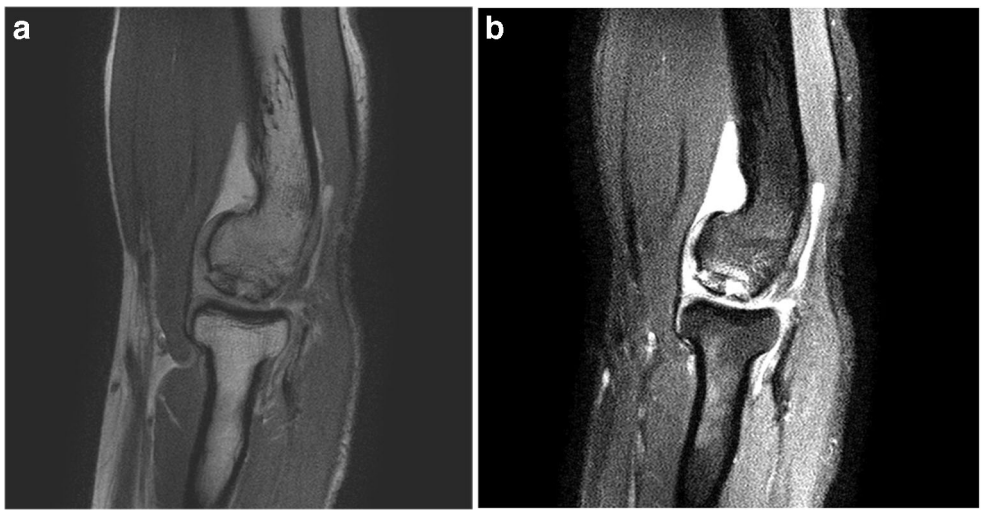

Fig. 3 **a** Sagittal T1 MRI image of a 16-year-old gymnast after failed loose body removal and microfracture. **b** Sagittal T2 MRI image of the same patient

Assessing Treatment Failure

General Principles

Based on the literature above, there are certain groups that are more susceptible for treatment failure who may require more aggressive treatment strategies: older patients with closed capitellar physes, patients with a longer pre-operative duration of symptoms, and those involved in higher risk upper extremity sports (baseball/gymnastics).

As with any operative pathology in the active pediatric and adolescent population, modifiable risk factors for treatment failure must be identified. Non-compliance and/or non-adherence to physical therapy protocols and activity restrictions is all associated with need for repeat surgery. Finally, the sport of choice also plays a significant role. Individuals involved in high-impact upper extremity activities such as baseball and gymnastics [24] who chose to return to these activities continue to expose their elbow to repetitive trauma and treatment failure. In these cases, the orthopedic surgeon plays a critical role in counseling the patient about the risks of ongoing symptoms despite successful surgical intervention.

Revision surgery is done for a number of reasons, including ongoing pain and symptoms as well as radiographic evidence of poor healing. In the case of return to the operating room, orthopedists must therefore identify the modifiable factors to improve the chances for healing and functional success.

Failure of Primary Fixation

Intra-operative assessment of the viability of lesion (both unstable and/or loose bodies) can be challenging. The surgeon at the time of index surgery must look for a piece which can be anatomically replaced into its donor site, has attached subchondral bone (although reports of chondral-only fixation in the knee have been reported [31]), and is small (less than 9–13 mm) [19, 20•]. If primary fixation fails, the fragment and all non-viable tissue must be removed including implants. The donor site must be assessed for size and viability with consideration for either osteochondral autograft or allograft procedures. With the guarded outcomes of primary loose body removal and microfracture in the literature [17–19, 20•], the utilization of this technique in the revision setting should be limited in lieu of aggressive cartilage restoration.

Failure of Osteochondral Autograft Procedures

Continued pain, decreased functional ability, and failure of radiographic healing after osteochondral autograft procedures must be vigorously analyzed once modifiable risk factors, including physical therapy compliance and premature return to sport, have been excluded. Matsuura et al. compared outcomes of 87 juvenile athletes who underwent an OATS procedure for central versus lateral lesions of the capitellum [32••]. More patients in the lateral group had post-operative radial head subluxation, worse extension, lower outcomes scores, and osteoarthritic changes compared with the central group. These findings were also supported by Shi et al. who examined 43 adolescent elbows comparing outcomes of contained (surrounding by intact articular cartilage) and uncontained (extending beyond the lateral cartilaginous margin) lesions [33]. The authors found a trend toward uncontained lesions being shallower and larger, with patients having greater flexion contractures post-operatively.

Thus, patients with lateral/uncontained lesions must be counseled at the time of an OATS procedure that the expected post-operative outcomes may be lower and/or that different surgical strategies such as osteochondral allograft and/or activity changes post-operatively to maximize function must be considered.

Recognition of Complex Pathology

Assessment of Alignment

In the setting of failed surgical intervention, alignment at the elbow must be also considered. Although the utilization of upper extremity osteotomy procedures to off-load cartilaginous pathology in the elbow is not as commonly performed as in the knee (this can be largely be postulated to be due to the weight-bearing nature of the knee as well as both the complex neurovascular structures and three-dimensional anatomy of the elbow), this must be considered as well in the setting of failed surgery. Lau et al. found that compared with control patients, adolescent patients with capitellar OCD lesions had more varus carrying angles and more valgus at the distal humeral articular surface [34]. Various joint re-alignment procedures have been described including closed-wedge osteotomies of the distal humerus [35] as well as radial shortening [36] to off-load stress on the injured area.

Identification of Concurrent Pathology

In addition to alignment, additional pathology that can be a source of pain or decreased functional after surgery must be evaluated. Wu et al. examined 86 elbows in patients who were treated for capitellar OCDs and found radial head lesions in 30% of the elbows, predominantly in the anterior radial head. Those elbows that had radial head lesions that underwent OATS procedures had a trend toward improved motion and fewer mechanical symptoms that those that underwent drilling [37] (Fig. 4a, b). This pathology must be considered when evaluating osteochondral lesions both before and after failed treatment. In addition, careful examination for concomitant ligamentous injury is important to determine if increased

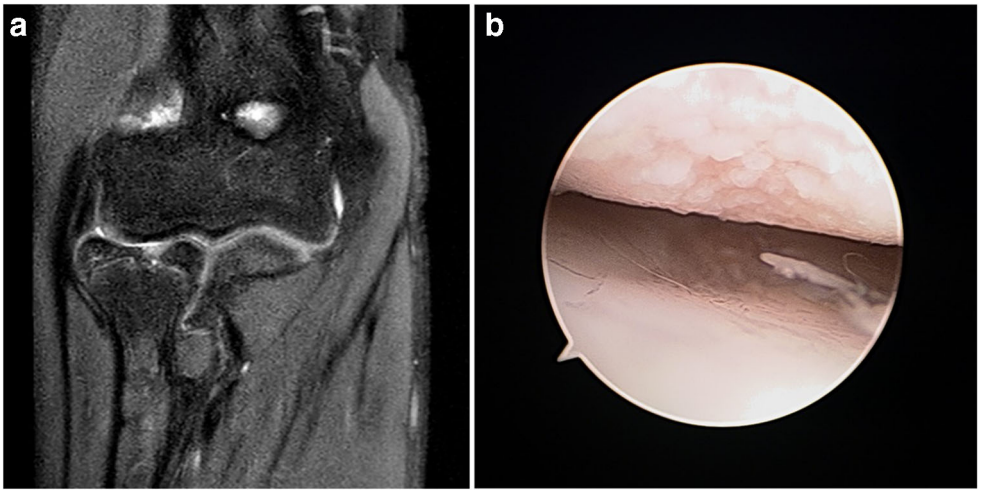

Fig. 4 **a** Coronal T2 MRI image of a 15-year-old male lacrosse player with both radial head and capitellar osteochondral injury. **b** Arthroscopic images at the time of surgery of the lesions in the radial head and capitellum

torque across the elbow joint is causing osteochondral injury in the absence of abnormal mechanics or overuse [38, 39].

Optimizing Outcomes After Revision

Post-operative Rehabilitation

Criteria for return to play after treatment of primary as well as revision treatment of capitellar lesions are limited due to variations in technique, rehabilitation protocols, and outcome measures [40•]. In general, an extended course of rehabilitation is recommended until clinical and radiographic healing is evident. A complete analysis of modifiable risk factors including upper extremity motion analysis and biomechanical evaluation is helpful. A sport-specific physical therapy regimen is critical to the patient's success with goals for optimizing the athlete's biomechanics. Careful counseling around activity modification, particularly changing either sport or position (particularly with baseball players and gymnasts) is critical.

Conclusion

Osteochondral lesions of the capitellum in the pediatric and adolescent population remain difficult entities to treat for the orthopedic surgeon. Careful counseling in regard to participation in post-operative high-demand activity is critical. In addition, minimizing primary treatment failure can maximize patient outcome. Avoidance of fixation of large osteochondral fragments, limited use of loose body removal/microfracture, and minimizing OATS procedures in uncontained/lateral lesions are critical. If treatment failure does occur and patient compliance/post-operative rehabilitation has been optimized, aggressive cartilage restoration with OATS and recognition of pathologic alignment with osteotomy as needed, along with treatment and identification of radial head and ligamentous pathology, are paramount. Armed with a critical eye, treatment of pediatric and adolescent patients with capitellar OCD lesions can lead to high levels of clinical and radiographic healing.

Compliance with Ethical Standards

Conflict of Interest Eric Chen declares that he has no conflict of interest. Nirav Pandya is a consultant for Orthopediatrics.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Pasulka J, Jayanthi N, McCann A, Dugas LR, LaBella C. Specialization patterns across various youth sports and relationship to injury risk. Phys Sportsmed. 2017;45:344–52. https://doi.org/10.1080/00913847.2017.1313077.
2.•• Bell DR, Post EG, Biese K, Bay C, Valovich McLeod T. Sport specialization and risk of overuse injuries: a systematic review with meta-analysis. Pediatrics. 2018;142. https://doi.org/10.1542/peds.2018-0657 **This meta-analysis demonstrated the sports specialization is associated with an increased risk of overuse injuries.**
3.•• Post EG, Trigsted SM, Riekena JW, Hetzel S, McGuine TA, Brooks MA, et al. The association of sport specialization and training volume with injury history in youth athletes. Am J Sports Med. 2017;45:1405–12. https://doi.org/10.1177/0363546517690848 **This case-control study of 2011 athletes demonstrated that athletes who played their primary sport more than 8 months of the year were more likely to report upper (OR = 1.68) or lower (OR = 1.66) extremity injury. Athletes who played more sports per week than their age were also more likely to report an injury of any type (OR = 1.34).**

4.•• Agresta CE, Krieg K, Freehill MT. Risk factors for baseball-related arm injuries: a systematic review. Orthop J Sports Med. 2019;25: 2325967119825557. https://doi.org/10.1177/2325967119825557 **This systematic review of 14 studies found that pitching > 100 innings in 1 year, being aged 9 to 11 years, being a pitcher or catcher, training > 16 h per week, and having a history of elbow pain were significant risk factors for elbow injury among youth players.**

5. Dekker TJ, Godin JA, Dale KM, Garrett WE, Taylor DC, Riboh JC. Return to sport after pediatric anterior cruciate ligament reconstruction and its effect on subsequent anterior cruciate ligament injury. J Bone Joint Surg Am. 2017;99:897–904. https://doi.org/10.2106/JBJS.16.00758.

6. Kramer J, Gajudo G, Pandya NK. Risk of recurrent instability after arthroscopic stabilization for shoulder instability in adolescent patients. Orthop J Sports Med. 2019;7:2325967119868995. https://doi.org/10.1177/2325967119868995.

7. Nissen CW. Osteochondritis dissecans of the elbow. Clin Sports Med. 2014;33:251–65. https://doi.org/10.1016/j.csm.2013.11.002.

8.• Kida Y, Morihara T, Kotoura Y, Hojo T, Tachiiri H, Sukenari T, et al. Prevalence and clinical characteristics of osteochondritis dissecans of the humeral capitellum among adolescent baseball players. Am J Sports Med. 2014;42:1963–71. https://doi.org/10.1177/0363546514536843 **This study of 2433 adolescent baseball players found a prevalence of OCD of 3.4%. Those affected had started playing baseball at a younger age for longer periods and had suffered from elbow pain.**

9. Matsuura T, Iwame T, Suzue N, Takao S, Nishio S, Arisawa K, et al. Cumulative incidence of osteochondritis dissecans of the capitellum in preadolescent baseball players. Arthroscopy. 2019;35:60–6. https://doi.org/10.1016/j.arthro.2018.08.034.

10.•• Kessler JI, Jacobs JC Jr, Cannamela PC, Weiss JM, Shea KG. Demographics and epidemiology of osteochondritis dissecans of the elbow among children and adolescents. Orthop J Sports Med. 2018;6:2325967118815846. https://doi.org/10.1177/2325967118815846 **This population-based cohort study found that males and patients between the ages of 12 and 19 had higher risk for development of elbow OCD.**

11.• Matsuura T, Suzue N, Iwame T, Nishio S, Sairyo K. Prevalence of osteochondritis dissecans of the capitellum in young baseball players: results based on ultrasonographic findings. Orthop J Sports Med. 2014;2:2325967114545298. https://doi.org/10.1177/2325967114545298 **In this ultrasound study of 1040 players, the prevalence of capitellar OCD was 2.1% in ages 10–12.**

12. Dexel J, Marschner K, Beck H, Platzek I, Wasnik S, Schuler M, et al. Comparative study of elbow disorders in young high-performance gymnasts. Int J Sports Med. 2014;35:960–5. https://doi.org/10.1055/s-0034-1371835.

13.• Weiss JM, Nikizad H, Shea KG, Gyurdzhyan S, Jacobs JC, Cannamela PC, et al. The incidence of surgery in osteochondritis dissecans in children and adolescents. Orthop J Sports Med. 2016;4:2325967116635515. https://doi.org/10.1177/2325967116635515 **Fifty-five percent of all elbow OCDs in this retrospective study progressed to surgery, much higher than other joints in this study.**

14. Krause M, Hapfelmeier A, Möller M, Amling M, Bohndorf K, Meenen NM. Healing predictors of stable juvenile osteochondritis dissecans knee lesions after 6 and 12 months of nonoperative treatment. Am J Sports Med. 2013;41:2384–91. https://doi.org/10.1177/0363546513496049.

15. Duqin TR, O'Driscoll SQ. Retrograde drilling for the treatment of capitellar osteochondritis dissecans. Arthroscopy. 2011;27(supplement):e56–7. https://doi.org/10.1016/j.arthro.2011.03.054.

16. Tis JE, Edmonds EW, Bastrom T, Chambers HG. Short-term results of arthroscopic treatment of osteochondritis dissecans in skeletally immature patients. J Pediatr Orthop. 2012;32:226–31. https://doi.org/10.1097/BPO.0b013e31824afeb8.

17. Koehler SM, Walsh A, Lovy AJ, Pruzansky JS, Shukla DR, Hausman MR. Outcomes of arthroscopic treatment of osteochondritis dissecans of the capitellum and description of the technique. J Shoulder Elb Surg. 2015;24:1607–12. https://doi.org/10.1016/j.jse.2015.06.013.

18. Uchida S, Utsunomiya H, Taketa T, Sakoda S, Hatakeyama A, Nakamura T, et al. Arthroscopic fragment fixation using hydroxyapatite/poly-L-lactate acid thread pins for treating elbow osteochondritis dissecans. Am J Sports Med. 2015;43:1057–65. https://doi.org/10.1177/0363546515570871.

19. Nobuta S, Ogawa K, Sato K, Nakagawa T, Hatori M, Itoi E. Clinical outcome of fragment fixation for osteochondritis dissecans of the elbow. Ups J Med Sci. 2008;113:201–8.

20.• Hennrikus W, Miller P, Micheli L, Waters P, Bae D. Internal fixation of unstable in situ osteochondritis dissecans lesions of the capitellum. J Pediatr Orthop. 2015;35:467–73. https://doi.org/10.1097/BPO.0000000000000308 **In this retrospective case series, young patients with in situ OCD lesions < 13 mm in sagittal width had excellent outcomes with internal fixation.**

21. Wulf CA, Stone RM, Giveans MR, Lervick GN. Magnetic resonance imaging after arthroscopic microfracture of capitellar osteochondritis dissecans. Am J Sports Med. 2012;40:2549–56. https://doi.org/10.1177/0363546512458765.

22.•• Bexkens R, van den Ende KIM, Ogink PT, van Bergen CJA, van den Bekerom MPJ, Eygendaal D. Clinical outcome after arthroscopic debridement and microfracture for osteochondritis dissecans of the capitellum. Am J Sports Med. 2017;45:2312–8. https://doi.org/10.1177/0363546517704842 **In this study of 81 elbows which underwent debridement and microfracture for OCD lesions, only 62% of patients returned to sports. Patients with open physes and shorter duration of symptoms who underwent loose body removal did better.**

23.•• Lewine EB, Miller PE, Micheli LJ, Waters PM, Bae DS. Early results of drilling and/or microfracture for grade IV osteochondritis dissecans of the capitellum. J Pediatr Orthop. 2016;36:803–9 **In this study of 21 elbows treated with drilling or microfracture, shorter duration of symptoms correlated with small OCD lesions as well as improved clinical and radiographic outcomes.**

24. Pandya NK, Bryant J. Outcomes of surgical treatment of osteochondral lesions of the elbow in pediatric and adolescent athletes. Abstract presented at Pediatric Research in Sports Medicine National Meeting. Fort Lauderdale, Florida. 2018.

25.•• Bae DS, Ingall EM, Miller PE, Eisenberg K. Early results of single-plug autologous osteochondral grafting for osteochondritis dissecans of the capitellum in adolescents. J Pediatr Orthop. 2018. https://doi.org/10.1097/BPO.0000000000001114 **In this study of 28 patients who underwent single-plug OATS, patients with > 6-month follow-up, 100% had returned to sport with no complications.**

26.•• Lyons ML, Werner BC, Gluck JS, Freilich AM, Dacus AR, Diduch DR, et al. Osteochondral autograft plug transfer for treatment of osteochondritis dissecans of the capitellum in adolescent athletes. J Shoulder Elbow Surg. 2015;24:1098–105. https://doi.org/10.1016/j.jse.2015.03.014 **Eleven patients with large (> 1 cm^2) OCD lesions underwent OATS procedures with 100% return to pre-injury level of play at a mean of 4.4 months after the procedure.**

27. 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;34:714–20.

28.• 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;42:2122–7. https://doi.org/10.1177/0363546514538759 **In this retrospective review of 33 patients who underwent an OATS procedure, all but two patients returned to pre-injury level of sport at a mean of 6.9 months after surgery.**

29. Iwasaki N, Kato H, Ishikawa J, Saitoh S, Minami A. Autologous osteochondral mosaicplasty for capitellar osteochondritis dissecans in teenaged patients. Am J Sports Med. 2006;34:1233–9.
30. Mirzayan R, Lim MJ. Fresh osteochondral allograft transplantation for osteochondritis dissecans of the capitellum in baseball players. J Shoulder Elbow Surg. 2016;25:1839–47. https://doi.org/10.1016/j.jse.2016.08.006.
31. Fabricant PD, Yen YM, Kramer DE, Kocher MS, Micheli LJ, JTR L, et al. Fixation of traumatic chondral-only fragments of the knee in pediatric and adolescent athletes: a retrospective multicenter report. Orthop J Sports Med. 2018;6:2325967117753140. https://doi.org/10.1177/2325967117753140.
32.•• Matsuura T, Hashimoto Y, Nishino K, Nishida Y, Takahashi S, Shimada N. Comparison of clinical and radiographic outcomes between central and lateral lesions after osteochondral autograft transplantation for osteochondritis dissecans of the humeral capitellum. Am J Sports Med. 2017;45:3331–9. https://doi.org/10.1177/0363546517730358 **This was a comparison of 103 athletes who underwent an OATS procedure with either central or lateral lesions. Clinical and radiographic outcomes were found to be better for central lesions, particularly in regard to radial head subluxation, osteoarthritic changes, and return to sports.**
33. Shi LL, Bae DS, Kocher MS, Micheli LJ, Waters PM. Contained versus uncontained lesions in juvenile elbow osteochondritis dissecans. J Pediatr Orthop. 2012;32:221–5. https://doi.org/10.1097/BPO.0b013e31824afecf.
34. Lau BC, Pandya NK. Radiographic comparison of adolescent athletes with elbow osteochondritis dissecans to ulnar collateral ligament injuries and controls. J Shoulder Elbow Surg. 2017;26:589–95. https://doi.org/10.1016/j.jse.2016.09.037.
35. Ueki M, Moriya K, Yoshizu T, Tsubokawa N, Kouda H, Endo N. Closed-wedge osteotomy of the distal humerus for treating osteochondritis dissecans of the capitellum in young patients. Orthop J Sports Med. 2019;7:2325967119876247. https://doi.org/10.1177/2325967119876247.
36. Diab M, Poston JM, Huber P, Tencer AF. The biomechanical effect of radial shortening on the radiocapitellar articulation. J Bone Joint Surg Br. 2005;87:879–83.
37. Wu M, Eisenberg K, Williams K, Bae DS. Radial head changes in osteochondritis dissecans of the humeral capitellum. Orthop J Sports Med. 2018;6:2325967118769059. https://doi.org/10.1177/2325967118769059.
38. Duggan JP Jr, Osadebe UC, Alexander JW, Noble PC, Lintner DM. The impact of ulnar collateral ligament tear and reconstruction on contact pressures in the lateral compartment of the elbow. J Shoulder Elb Surg. 2011;20:226–33. https://doi.org/10.1016/j.jse.2010.09.011.
39. 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;41:1909–14. https://doi.org/10.1177/0363546513490652.
40.• 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;33:1412–1420.e1. https://doi.org/10.1016/j.arthro.2017.01.046 **This systematic review of return to play after OATS procedures found large variability in surgical techniques, post-operative rehabilitation protocols, and outcome assessment.**