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Trauma

Managing Recurrent Clavicle Nonunion and Construct Failure: A Case Report

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Case

A 36-year-old male who suffered a left midshaft clavicle fracture, following a fall from a mountain bike, was treated unsuccessfully with two ORIF surgeries. Smoking cessation and management of hypovitaminosis was addressed preoperatively before final revision with a dual plate construct and tibial autologous bone graft. Follow-up radiographs taken at 12 months from the initial surgery showed intact hardware and full bone healing.

Conclusion

Successful management of clavicle nonunions can be optimized through optimal plate selection, plate positioning, number of plates, construct biomechanics, biologic augmentation, and preoperative risk optimization. Efforts to minimize controllable risk

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factors for nonunion, such as smoking cessation or vitamin D supplementation, should be utilized both preoperatively and postoperatively.

INTRODUCTION

Treatment of midshaft clavicle fractures is either non-operative immobilization or operative with recent literature suggesting open reduction and internal fixation (ORIF) leads to better union rates and functional outcomes. A meta-analysis comparing non-operative and operative treatment of midshaft clavicle fractures found the nonunion rate to be 14.5% and 1.4% respectively.[1] Although nonunion of clavicle fractures following ORIF is an uncommon complication, when symptomatic, it can result in poor outcomes and debilitation of the upper extremity. Risk factors for nonunion include smoking, comminution, older age, and fracture displacement greater than 2cm.[2] The preferred treatment for symptomatic nonunion is surgical intervention, however, persistent nonunion can occur and has been associated with hardware failure, plate placement, type of implant utilized, and various patient specific risk factors.[3][4][5]

With operative treatment of clavicle fractures increasing in frequency, understanding the modes of failure of clavicular constructs is critical given the variety of plate options and positions. In this report, we present a unique case of a comminuted midshaft clavicle fracture treated multiple times with plate osteosynthesis following recurrent plate breakage. This case highlights the need for a holistic approach to clavicular nonunion, optimizing construct design as well as patient risk factors to achieve optimal bone healing. We also review the literature and discuss the incidence, causes, and treatment of clavicle nonunion.

Figure 1. Xray (AP) of the left clavicle showing a closed comminuted displaced midshaft fracture

CASE REPORT

A 36-year-old male presented with left shoulder pain after a high impact fall from a mountain bike. The patient had no other known illnesses and no previous injuries. Social history was significant for tobacco usage. On physical exam, there were no signs of neurovascular injury and AP and lateral radiographs confirmed the presence of a closed, comminuted, and displaced midshaft fracture of the left clavicle (Figure 1). Due to the degree of comminution and displacement of the fracture, surgical treatment was indicated. The two comminuted fragments were fixed with two lag screws and an 8-hole superior clavicle specific plate (Figure 2) without intraoperative complications.

The patient returned two and a half months after the initial surgery with discomfort in his left shoulder after

1 Robbin C. McKee et al., "Operative Versus Nonoperative Care of Displaced Midshaft Clavicular Fractures: A Meta-Analysis of Randomized Clinical Trials," *Journal of Bone and Joint Surgery* 94, no. 8 (April 18, 2012): 675–84, https://doi.org/10.2106/JBJS.J.01364.

2 IR Murray, CJ Foster, and A Eros, "Risk Factors for Nonunion after Nonoperative Treatment of Displaced Midshaft Fractures of the Clavicle," *J Bone Joint Surg Am* 13 (2013): 1153–58.

3 Michael D Mckee, Lisa M Wild, and Emil H Schemitsch, "Midshaft Malunions of the Clavicle," *VO LU M E*, 2003, 8.

4 Peter J. Millett et al., "Complications of Clavicle Fractures Treated with Intramedullary Fixation," *Journal of Shoulder and Elbow Surgery* 20, no. 1 (January 2011): 86–91, https://doi.org/10.1016/j.jse.2010.07.009.

5 Bipin Patel, Peter A. Gustafson, and James Jastifer, "The Effect of Clavicle Malunion on Shoulder Biomechanics; A Computational Study," *Clinical Biomechanics* 27, no. 5 (June 2012): 436–42, https://doi.org/10.1016/j.clinbiomech.2011.12.006.

Figure 2. Postoperative X-ray (AP) of left clavicle showing an 8-hole superior clavicle locking plate with screw fixation with continued visualization of fracture line.

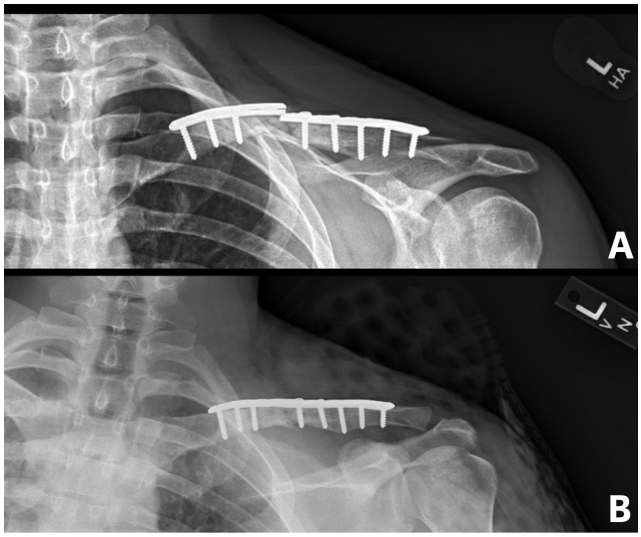

Figure 3. A. Xray (AP) of left clavicle 2.5 months after initial surgery showing remaining midshaft clavicle fracture with midplate breakage, and no loss of fixation; B. Radiograph taken after second revision surgery demonstrates a reduced clavicle fracture fixed with 10-hole superior clavicular locking plate.

hearing a snapping sound while exercising. Radiographs demonstrated persistence of the fracture at the original site with plate breakage (Figure 3-A). Given failure of fixation, the patient elected to proceed with a revision surgery which was performed two weeks later. Intraoperative examination of the clavicle showed fibrous nonunion with significant mobility. The fracture ends were debrided, and the clavicle was reduced and fixed with a 10-hole superior clavicular locking plate (Figure 3-B).

He initially did well following revision surgery, however 3 months later and 6 months following his initial surgery, the patient presented with discomfort and persistent pain over his left clavicle. Repeat radiography of the primary fracture site revealed a delayed union of the clavicle with plate breakage and fixation failure (Figure 4-A). The patient reported continued smoking throughout his postoperative period, and laboratory studies revealed no signs of infection and low levels of Vitamin D and alkaline phosphatase. After two surgical failures, non-operative interventions including supplementation to correct low vitamin D levels, activity modifications, and smoking cessation were implemented. Low intensity pulsed Ultrasound (LIPUS) bone stimulator was considered but was cost-prohibitive given lack of insurance coverage.

Seven months following the initial surgery and after one month of nonoperative management and smoking cessation, repeat radiographs showed no change (Figure 4-B). A third surgical intervention of ORIF with plate fixation with cancellous tibia bone autograft was planned for two weeks later. Smoking cessation was verified, and vitamin D supplementation was initiated prior to repeat revision surgery. Intraoperatively, the fracture site showed poor bone quality and significant fracture comminution. Existing hardware was removed, and a locking plate was provisionally placed anterior-inferiorly and secured with two bicortical screws (Figure 5-A). An Avitus bone graft harvester was then used to harvest cancellous bone and liquid bone marrow from the left proximal tibia crest. A small 1cm incision was made on the medial border of the tibial crest after which the pilot hole creator was used to create an 8mm cortical window in the tibia (Figure 5-B). The Avitus harvester was attached to standard OR suction and inserted into the tibia. Approximately 18-20ccs of autograft was harvested. The graft was used to fill the posterior and superior fracture gap and augment bone healing at fractures site (Figure 5-D). Three locking screws on each side of the fracture line were placed and then a second 7-hole locking plate was positioned on the superior aspect of the clavicle and secured with cortical and locking screws (Figure 6-A). The tibial cortical window site was filled with cancellous bone chips and back filled

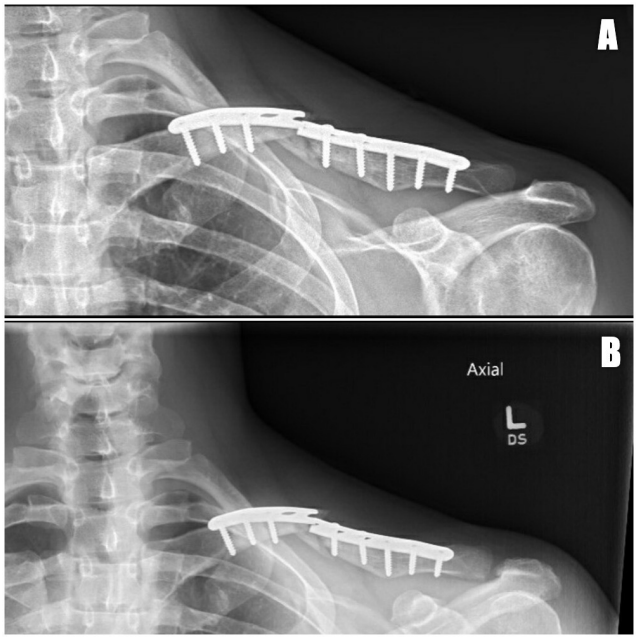

Figure 4. A. Xray (AP) 6 months after initial operation showing delayed nonunion at the primary fracture site and repeat plate breakage with failure of fixation; B. Xray at 7 months demonstrated no change from the previous visit.

with Hydroset bone substitute followed by closure of the cortical window (Figure 5-C, D).

Two months after the third surgical intervention and nine months after initial surgery, follow up radiographs showed intact hardware without interval change, appropriate alignment, and good interval healing at the fracture site (Figure 6-B). The treatment plan continued with electromagnetic bone growth stimulator, oral Vitamin D supplementation, graduated physical therapy, and continued tobacco smoking cessation. One and a half years after initial surgery, radiographs showed intact hardware and good bone healing (Figure 6-C).

DISCUSSION

Historically, incidence rates of nonunion following nonoperative management of clavicle fractures have been cited as less than 1% however recent studies have found that for specific fracture subtypes, the incidence rate may be much higher.[6789] Although nonunion rates following ORIF are significantly lower than nonoperative treatment, a systemic review of 11 studies found that clavicular nonunion after plate fixation of a displaced midshaft clavicular fracture (DMCF) occurs in less than 10% of cases for all studies except one.[10] Nonoperative management of clavicle nonunion consists of fracture bracing/immobilization supplemented with LIPUS or other external bone stimulator. Rates of fracture healing in chronic bone nonunion with LIPUS have

6 Rowe, CR, "An Atlas of Anatomy and Treatment of Midclavicular Fractures.1968;58:29–42.," *Clin Orthop* 58 (1968): 29–42.

7 Charles Neer, "Nonunion of the Clavicle," *J Am Med Assoc* 172 (1960): 1006–11.

8 McKee et al., "Operative Versus Nonoperative Care of Displaced Midshaft Clavicular Fractures."

9 Murray, Foster, and Eros, "Risk Factors for Nonunion after Nonoperative Treatment of Displaced Midshaft Fractures of the Clavicle."

10 Frans-Jasper G. Wijdicks et al., "Systematic Review of the Complications of Plate Fixation of Clavicle Fractures," Arch Orthop Trauma Surg 123, no. 5 (2012): 617–25.

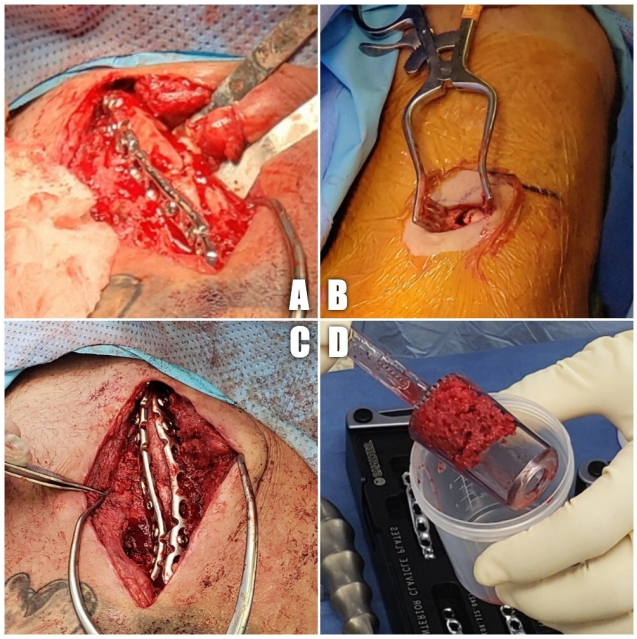

Figure 5. A. In the third operation, initial left clavicle fixation by anterior plate prior to autogenous bone graft; B. Proximal tibial graft site following collection of autogenous bone graft; C. Left clavicle dual plate fixation by anterior and superior plates; D. Autogenous cancellous bone and bone marrow graft collected by Avitus bone harvester.

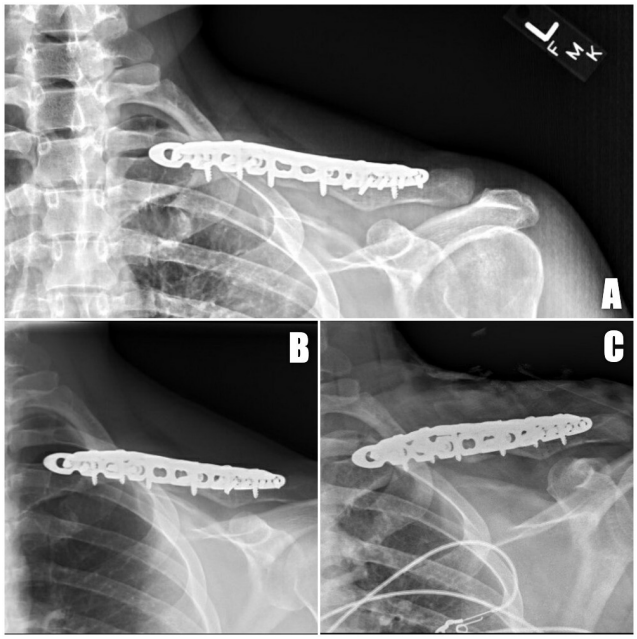

Figure 6. A. Postoperative X-ray showing a second 7-holelocking plate secured to the superior aspect of the clavicle, in addition to the previously fixed anterior locking plate, which was sequentially secured with cortical and locking screws; B. Follow-up radiographs taken at 9months from the initial fracture showed intact hardware without interval change, appropriate alignment without displacement, and positive callous formation; C. Follow-up radiographs taken at 12 months from the original fracture showed intact hardware and continuous bone recovery.

been reported as high as 82%.[11] The majority of clavicle nonunions are treated with revision ORIF however reoperation is associated with a higher rate of short-term complications compared to ORIF of acute fractures.[12] Given this higher rate of complications and the patient burden associated with surgical correction of nonunion, it is imperative to understand the factors that predispose to nonunion and optimize success in revision surgery.

RISK OPTIMIZATION

Bone healing is a complex interplay between osteogenic cells, osteoconductive scaffolding, adequate growth factors, and mechanical stability.[13] Patient specific factors, such as smoking and low vitamin D levels, increase the risk of failed osteosynthesis due to deleterious effects on bone healing. Jarvis et al. highlighted smoking as the only identifiable risk factor for postoperative failure of osteosynthesis regardless of the fixation device.[14] Systematic reviews have shown that smoking increases the time to union and risk of nonunion by 40% when compared to non-smokers and thus recommend smoking cessation at least 4 weeks prior to surgery.[151617] In addition to smoking, studies have shown

11 Zura, Robert, et al. "Treatment of chronic (> 1 year) fracture nonunion: heal rate in a cohort of 767 patients treated with low-intensity pulsed ultrasound (LIPUS)." Injury 46.10 (2015): 2036-2041.

12 Braden McKnight et al., "Surgical Management of Midshaft Clavicle Nonunions Is Associated with a Higher Rate of Short-Term Complications Compared with Acute Fractures," Journal of Shoulder and Elbow Surgery 25, no. 9 (September 2016): 1412–17, https://doi.org/10.1016/j.jse.2016.01.028.

13 P.V. Giannoudis, T.A. Einhorn, and D. Marsh, "Fracture Healing: The Diamond Concept," *Injury* 38, no. Suppl 4 (2007): S3–6.

14 Neil E. Jarvis et al., "Surgery for the Fractured Clavicle: Factors Predicting Nonunion," *J Shoulder Elbow Surg* 27, no. 5 (2018): e155–59.

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16 Moghaddam et al., "Cigarette Smoking Influences the Clinical and Occupational Outcome of Patients with Tibial Shaft Fractures."

17 Bin Xu et al., "The Influence of Smoking and Alcohol on Bone Healing: Systematic Review and Meta-Analysis of Non-Pathological Fractures," *EClinicalMedicine* 42 (December 2021): 101179, https://doi.org/10.1016/j.eclinm.2021.101179.

low levels of vitamin D delay bone union clinically.[18] [19] [20] In a recent study of over 300,000 fractures, nonunion was significantly increased in patients with vitamin D deficiency for all 18 bones analyzed (OR, 1.14; 95% CI, 1.05-1.22) and the nonunion rate was higher in clavicle fractures when compared to the average fracture (8.2% vs 4.9%).[21]

DUAL PLATING

Dual plating with reconstruction plates is biomechanically superior to single plating.[22] A commonly used plate combination is a 2.7mm or 3.5mm reconstruction plate placed anteriorly with a 2.0mm or 2.4mm mini-fragment plate placed superiorly.[23] Use of a mini-fragment plate superiorly leads to low rates of implant irritation. Several studies in the literature have found higher union rates, lower incidence of implant irritation, and lower nonunion rates with dual plating when compared to single plating.[24] [25] [26] However, a retrospective review of 20 patients with symptomatic clavicular non-union by Sadiq et al found no difference in the use of single or dual-plate constructs with all patients achieving bony union.[27]

PLATE TYPES

The most common implants utilized in midclavicular ORIF are anatomic specific locking/nonlocking plates, locking plates, dynamic compression plates (DCPs), pre-contoured locking compression plates (LCPs), and reconstruction plates. While reconstruction plates have a lower profile and fit the contour of the clavicle, the reduced plate stiffness can lead to implant failure.[28] In two multi-center randomized controlled studies, pre-contoured LCPs had failure rates much lower at 1.1% and 0.6%.[29] DCPs are stronger, but their straight shape causes implant prominence and irritation.[30] Since LCPs are anatomically contoured, they cause less irritation and their resistance to deformity may decrease implant failure.[31] DCPs and LCPs both feature increased stiffness and cantilever bending failure load when compared to reconstruction plates.[32] [33]

BONE GRAFT SUPPLEMENTATION

While autologous bone grafts remain the gold standard for treating delayed union and nonunion of fractures, bone grafts and cell-based therapies can be also be utilized to treat delayed union or nonunions. The Reamer-Irrigator-Aspirator (RIA) system, developed in the 1990s, was designed to harvest intramedullary bone graft from femoral

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18 C Tauber et al., "Blood Levels of Active Metabolites of Vitamin D3 in Fracture Repair in Humans A Preliminaryreport," n.d., 3.

19

20 Hojjat Hossein Pourfeizi et al., "Prevalence of Vitamin D Deficiency and Secondary Hyperparathyroidism in Nonunion of Traumatic Fractures," n.d., 6.

21 Robert Zura et al., "Epidemiology of Fracture Nonunion in 18 Human Bones," *JAMA Surgery* 151, no. 11 (November 16, 2016): e162775, https://doi.org/10.1001/jamasurg.2016.2775.

22 Parvan Yanev et al., "Two Reconstruction Plates Provide Superior Stability of Displaced Midshaft Clavicle Fractures in Comparison to Single Plating – A Biomechanical Study," *Clinical Biomechanics* 80 (December 2020): 105199, https://doi.org/10.1016/j.clinbiomech.2020.105199.

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24 Xiaobin Chen et al., "Radiographic Outcomes of Single versus Dual Plate Fixation of Acute Mid-Shaft Clavicle Fractures," *Archives of Orthopaedic and Trauma Surgery* 137, no. 6 (June 2017): 749–54, https://doi.org/10.1007/s00402-017-2676-0.

25 Yunqiang Zhuang et al., "Management of Comminuted Mid-Shaft Clavicular Fractures: Comparison between Dual-Plate Fixation Treatment and Single-Plate Fixation," *Journal of Orthopaedic Surgery* 28, no. 2 (January 1, 2020): 230949902091579, https://doi.org/10.1177/2309499020915797.

26 Steven F. Shannon et al., "Extraperiosteal Dual Plate Fixation of Acute Mid-Shaft Clavicle Fractures: A Technical Trick," *Journal of Orthopaedic Trauma* 30, no. 10 (October 2016): e346–50, https://doi.org/10.1097/BOT.0000000000000633.

27 S Sadiq et al., "SINGLE OR DOUBLE PLATING FOR NONUNION OF THE CLAVICLE" 67 (2001): 8.

28 Yung-Cheng Chiu et al., "Comparison of Implant Failure Rates of Different Plates for Midshaft Clavicular Fractures Based on Fracture Classifications," *J Orthop Surg Res* 14 (2019): 220.

29

30 Rizwan Shahid, Abid Mushtaq, and Mohammad Maqsood, "Plate Fixation of Clavicle Fractures : A Comparative Study between Reconstruction Plate and Dynamic Compression Plate" 73 (2007): 5.

31 Yung-Cheng Chiu et al., "Comparison of Implant Failure Rates of Different Plates for Midshaft Clavicular Fractures Based on Fracture Classifications," *Journal of Orthopaedic Surgery and Research* 14, no. 1 (December 2019): 220, https://doi.org/10.1186/s13018-019-1259-x.

32 M.R. Iannotti et al., "Effects of Plate Location and Selection on the Stability of Midshaft Clavicle Osteotomies: A Biomechanical Study," *Journal of Shoulder and Elbow Surgery* 11, no. 5 (September 2002): 457–62, https://doi.org/10.1067/mse.2002.125805.

33 Lars Eden et al., "Biomechanical Comparison of the Locking Compression Superior Anterior Clavicle Plate with Seven and Ten Hole Reconstruction Plates in Midshaft Clavicle Fracture Stabilisation," *International Orthopaedics* 36, no. 12 (December 2012): 2537–43, https://doi.org/10.1007/s00264-012-1671-x.

and tibial donor sites. While it offers continuous irrigation and suction during the reaming of bone, several studies have reported donor site complications and disruption in the integrity of the collected graft.[34][35][36][37][38][39][40][41][42] More recently developed devices with similar capabilities, such as the Avitus Bone Harvester, have been introduced. To the best of our knowledge, this is the first instance of its use for clavicle nonunion described in the literature. A benefit of the Avitus Bone Harvester is it allows for the collection of a graft of cancellous bone from a small cortical access window using standard OR suction without irrigation diluting biologically active factors. Similar to other autograft harvesting techniques, there is a risk of donor site morbidity.

Open surgery with internal fixation and bone grafting for clavicle nonunion has been reported to be an acceptable technique that provides good final clinical outcome. While autogenous iliac crest bone graft is considered the gold standard, it has disadvantages such as limited volume of available bone and donor site morbidity.[43] Endrizzi et al reported 47 patients with clavicle nonunion treated with plate fixation. All patients were treated with local bone graft or demineralized bone matrix alone, and 44 (93%) of patients were found to have fracture union.[44] Similarly in 2017, Rollo et al examined 36 patients with clavicle nonunions managed with clavicular allograft and found all cases except 1 healed within 3 months.[45] Future studies could perform comparative analyses of plate type, size, position, dual plating, and use of adjuvants such as bone graft or stimulators on outcomes for nonunion.

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34 Mohan V. Belthur et al., "Bone Graft Harvest Using a New Intramedullary System," *Clinical Orthopaedics & Related Research* 466, no. 12 (December 2008): 2973–80, https://doi.org/10.1007/s11999-008-0538-3.

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37 Newman et al., "A New Minimally Invasive Technique for Large Volume Bone Graft Harvest for Treatment of Fracture Nonunions."

38 Todd A. McCall et al., "Treatment of Large Segmental Bone Defects with Reamer-Irrigator-Aspirator Bone Graft: Technique and Case Series," *Orthopedic Clinics of North America* 41, no. 1 (January 2010): 63–73, https://doi.org/10.1016/j.ocl.2009.08.002.

39 Sabine Wenisch et al., "Human Reaming Debris: A Source of Multipotent Stem Cells," *Bone* 36, no. 1 (January 2005): 74–83, https://doi.org/10.1016/j.bone.2004.09.019.

40 Johanna C. E. Donders et al., "Hemorrhagic-Induced Cardiovascular Complications During Reamer–Irrigator–Aspirator-Assisted Femoral Nonunion Treatment," *Journal of Orthopaedic Trauma* 30, no. 9 (September 2016): e294–98, https://doi.org/10.1097/BOT.0000000000000612.

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42 Patrick Haubruck et al., "Complications and Risk Management in the Use of the Reaming-Irrigator-Aspirator (RIA) System: RIA Is a Safe and Reliable Method in Harvesting Autologous Bone Graft," ed. Gunasekaran Kumar, *PLOS ONE* 13, no. 4 (April 26, 2018): e0196051, https://doi.org/10.1371/journal.pone.0196051.

43 Giuseppe Rollo et al., "Clavicle Aseptic Nonunion: Is There a Place for Cortical Allogenic Strut Graft?," *Injury* 48 (October 2017): S60–65, https://doi.org/10.1016/S0020-1383(17)30660-5.

44 Donald P. Endrizzi et al., "Nonunion of the Clavicle Treated with Plate Fixation: A Review of Forty-Seven Consecutive Cases," *Journal of Shoulder and Elbow Surgery* 17, no. 6 (November 2008): 951–53, https://doi.org/10.1016/j.jse.2008.05.046.

45 Rollo et al., "Clavicle Aseptic Nonunion."

CONCLUSION

This case is a unique example of a recurrent clavicular nonunion complicated by repeat construct failure. Though overall incidence is rare, clavicular nonunion is a difficult complication for patients that can likely be prevented by strategic management and screening of patients with high preoperative risk. Our primary recommendation is that efforts be made to minimize controllable risk factors for nonunion preoperatively. We recommend patients be advised on smoking cessation advice both preoperatively and postoperatively.

Given the high rates of union following bone grafting currently reported by literature and the modern availability of harvesting devices with minimal complication rates, it is reasonable to consider bone grafting following a first incidence of nonunion. In addition, increased reporting of clavicular nonunion cases is warranted and should focus on determining a causative relationship between nonunion and construct failure following ORIF.

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