Review Article

Management of Midshaft Clavicle Fractures in Adults

Brent Wiesel, MD
Sameer Nagda, MD
Samir Mehta, MD
Ryan Churchill, MD

Abstract

Fractures of the clavicle are common injuries that occur across all age groups but are most frequently seen in the young, active patient population. Among the different types of clavicle fractures, those occurring in the middle third of the clavicular shaft are the most common. Historically, most of these fractures were treated by closed means even when notable displacement was present. Recently, there has been a renewed interest in assessing the best treatment option for these patients. Although nonsurgical treatment is a reliable method for treating many of these fractures, more recent data suggest that fractures with notable displacement (>2 cm of shortening or >100% displacement) and/or comminution have better short-term outcomes and lower rates of nonunion with surgical management. Current surgical options include superior plating, anterior-inferior plating, dual plating, and intramedullary nail fixation.

From the MedStar Georgetown University Hospital, Washington, DC (Dr. Wiesel and Dr. Churchill), the Anderson Orthopaedic Clinic, Alexandria, VA (Dr. Nagda), and the Hospital of the University of Pennsylvania, Philadelphia, PA (Dr. Mehta).

Dr. Mehta or an immediate family member is a member of a speakers' bureau or has made paid presentations on behalf of Zimmer Biomet, Smith & Nephew, and AO North America; serves as a paid consultant to Smith & Nephew and DePuy Synthes; has received research or institutional support from Amgen, Medtronic, and Smith & Nephew; and serves as a board member, owner, officer, or committee member of the Pennsylvania Orthopaedic Society. None of the following authors nor any immediate family member has received anything of value from or has stock or stock options held in a commercial company or institution related directly or indirectly to the subject of this article: Dr. Wiesel, Dr. Nagda, and Dr. Churchill.

J Am Acad Orthop Surg 2018;26: e468-e476

DOI: 10.5435/JAAOS-D-17-00442

Fractures of the clavicle constitute an estimated 2% to 10% of all fractures in adults and are more common in younger, active individuals.[1] Of these fractures, 80% occur in middle third of the clavicle. Traditionally, most of these fractures were treated nonsurgically.[1,2] Neer and Rowe each published large-volume retrospective, cohort studies demonstrating 0.1% and 0.8% nonunion rates with nonsurgical management of midshaft clavicle fractures. Rowe stated that "nonunion occurs, but is rare" and espoused the "excellent reparative powers" of the clavicle with nonsurgical treatment.[2,3] Recently, these numbers have been called into question. Several studies[1,4-7] have found a 15% to 20% nonunion rate with nonsurgical management of displaced midshaft clavicle fractures. In addition, these authors found that nonsurgical management of fractures with greater than 1.5 to 2 cm of shortening or greater than 100% displacement leads to decreased shoulder function and worse clinical outcomes.[1,4-7]

Over the past 10 years, a notable number of studies have attempted elucidating the optimal treatment for displaced middle third clavicle fractures. The Canadian Orthopaedic Trauma Society (COTS) published one of the first studies in 2007. They performed a randomized controlled trial (RCT) comparing nonsurgical treatment with open reduction and internal fixation (ORIF) in displaced midshaft clavicle fractures. They randomized 132 patients to either nonsurgical treatment or ORIF and found that the ORIF patients had better outcome scores, a shorter time to union (16.4 versus 28.4 weeks), lower rates of nonunion (3% versus 14.2%), and lower rates of malunion. In their study, they defined a displaced clavicle fracture as one that had no cortical contact between the fracture fragments.[1]

Since this study, a plethora of high-level studies have investigated surgical versus nonsurgical management of midshaft clavicle fractures and different methods of surgical fixation. The goals of this article were to review both surgical and nonsurgical treatment options for midshaft clavicle fractures and to evaluate the results of the numerous studies that have been published in the past decade to ascertain the optimal treatment options for these patients.

Patient Evaluation

The mechanism of injury for most clavicle fractures is a fall onto the lateral aspect of the shoulder. On examination, it is important to identify open fractures and impending open fractures in patients' with notable skin tenting. In addition, the rotator cuff should be evaluated by examining the patient for an external rotation lag sign and having the patient perform a belly press test. Furthermore, it is critical to perform a complete neurovascular assessment and evaluate the entire upper extremity.

Standard radiographic evaluation consists of dedicated clavicle films in the form of an AP film and an AP film with 20° of cephalic tilt. Although this allows for the adequate assessment of superior-inferior displacement and comminution, Fenlin and colleagues proposed that 45° cephalic and 45° caudal radiographs be obtained to better assess AP displacement. They found higher interobserver reliability with a four-view series in assessing fracture displacement.[8] Using this complete film series, the orthopaedic surgeon can accurately determine the percentage of superior displacement and amount of shortening of the fracture fragments. In addition, one should scrutinize the radiographs for other potential musculoskeletal injuries and be sure to look at the upper lung fields for a possible pneumothorax. In radiographs that demonstrate distraction at the fracture site, the physician should evaluate the patient for scapulothoracic dissociation.

Radiographic parameters that are relative indications for surgical intervention are greater than 2 cm of shortening, greater than 100% of displacement, a Z-type fracture pattern (a comminuted fracture with a displaced and rotated butterfly fragment interposed between the major fragments that can result in skin tenting), and notable comminution.[1,6] Nowak et al specifically found that displacement of midshaft clavicular fractures greater than 1 bone width (ie, 100%) was the strongest radiographic predictor of persistent symptoms and negative sequelae in patients.[5]

Clavicular motion aids in abduction and forward elevation of the arm, with most of its contribution occurring above 90°.[2] With elevation of the arm, the clavicle elevates 11° to 15°, retracts 15° to 29°, and rotates about its long axis at an average of 15° to 31°.[2] Eskola et al[9] made the connection between clavicular shortening and patient outcomes. They found that patients who had residual shortening greater than 15 mm had more pain and worse outcome scores. Chan et al[10] found that clavicular malunion with shortening led to an altered position of the scapula at rest, which could subsequently result in scapular dyskinesia. This specific relationship between clavicular shortening and scapular dyskinesia was investigated by Shields and colleagues in a cohort study comparing patients treated surgically versus nonsurgically. They found that scapular dyskinesis was present in 37.5% of their patients and that 67% of their nonsurgical cohort had symptomatic scapular dyskinesia. The authors felt that the scapular dyskinesis encountered in the nonsurgical cohort was a direct result of the clavicular shortening that occurred because of nonsurgical treatment.[11] In addition, several biomechanics studies have found that clavicular shortening results in an altered position of the scapula.[12-14] Matsumura et al[13] found that clavicular shortening as little as 10% could alter the position of the glenohumeral joint. Clinical studies have shown that shortening greater than 14 mm in women and 18 mm in men results in worse functional outcomes scores and decreased strength.[6,15]

Treatment

Nonsurgical

Nonsurgical management of midshaft clavicle fractures consists of sling immobilization or figure-of-eight bracing treatment. Rowe[2] described the methods for a figure-of-eight brace and stated that the goal of the brace was to elevate and extend the shoulder to bring the distal fragment to the proximal fragment. Since Rowe's article, several studies have compared the results of sling immobilization and figure-of-eight bracing treatment and found sling treatment to be superior.[16,17] Anderson et al[16] found that all fractures in their study united, but 36% of patients treated with figure-of-eight bracing treatment were unsatisfied compared with only 7% in the sling cohort. Ersen et al[17] performed an RCT comparing the figure-of-eight bracing treatment with sling immobilization and found that the figure-of-eight brace resulted in greater residual shortening and markedly increased pain and as such recommended that a sling be used for nonsurgical treatment.

Although rehabilitation protocols may differ in subtle aspects, most nonsurgically treated patients are allowed to perform shoulder passive range of motion, not above 90°, between weeks 2 through 6. At week 6, strengthening is begun, and the sling is discontinued with weight bearing typically allowed around three months and return to sport at 4 to 6 months from injury.[1,18]

Surgical

Since the COTS study, a plethora of studies have been conducted comparing nonsurgical with surgical management of displaced clavicle fractures. A common finding among these studies has been a higher nonunion rate than previously reported with nonsurgical management of these fractures. Fuglesang et al[19] retrospectively reviewed 92 patients with displaced midshaft clavicle fractures treated nonsurgically and had a 15.3% nonunion rate. Furthermore, 24% of patients had fair or poor Disabilities of the Arm, Shoulder and Hand scores, with 53% reporting residual pain at 2.7 years. One of their most important findings was a statistically significant correlation between patients with greater than 100% displacement and worse outcomes. Hill and colleagues reviewed 66 patients with an average of 38-month follow-up and found a 15% nonunion rate, with 31% of patients reporting unsatisfactory outcomes. They also found a significant correlation between nonunion and worse outcomes with initial fracture shortening greater than 2 cm. This phenomenon led them to recommend ORIF to patients with greater than 2 cm of shortening on initial radiographs.[4]

The results of these studies have led to several high-level RCTs and subsequent meta-analyses. Table 1 (see Supplemental Digital Content 1, http://links.lww.com/JAAOS/A125) summarizes the results of these RCTs and meta-analyses.[1,7,18,20-25] Although the results are not uniform, agreement exists among the studies on certain outcomes, the principal of which is a higher rate of nonunion with nonsurgical management of these fractures.

Before the study by the COTS, only two RCTs compared surgical with nonsurgical treatment.[7] In the COTS study, the surgical group was treated with a superiorly based plate, and the nonsurgical group was treated with a simple sling. They found that patients in the surgical group had a faster time to union, better outcome scores, and higher satisfaction compared with patients treated nonsurgically. Although these results are encouraging, they also noted complications including implant irritation, wound infection, and wound dehiscence in the surgical group.[1]

Smekal et al[22] and Judd et al[23] each published RCTs comparing intramedullary fixation with nonsurgical treatment. Judd et al[23] found that functional scores were higher only in the surgical group at 3 weeks, with no difference at the remaining time points, and a markedly higher number of complications were noted in the surgical group. Smekal used an elastic stable intramedullary nailing technique and found that compared with the nonsurgical group, the elastic stable intramedullary nailing group had a lower nonunion rate, statistically significantly better outcomes scores, and less residual clavicular shortening.[22]

In addition to a lower nonunion rate, three recent meta-analyses showed a trend toward better outcomes with surgical intervention, but a notable rate of secondary surgery for implant removal.[7,24,25] Appropriately, several studies have attempted to elucidate which patients will develop a symptomatic nonunion so as to better counsel patients. Robinson et al[26] analyzed 868 displaced clavicle fractures for factors associated with nonunion. They found that the lack of cortical apposition, female sex, comminution, and advanced age were associated with an increased risk of nonunion. Murray et al reviewed a cohort of 941 patients with displaced clavicle fractures and found that 125 patients went onto nonunion. After multivariate analysis, they identified smoking, comminution, and fracture displacement as factors markedly associated with nonunion. Furthermore, they found that if surgeons treated all displaced midshaft fractures surgically, the number needed to treat to avoid nonunion would be 7.5 patients, but if surgeons treated only those patients with a greater than 40% risk of nonunion, the number needed to treat decreased to 1.7.[27]

Surgical Techniques

When surgical intervention is undertaken, two general options for fixation exist: an intramedullary nail (IMN) or a plate and screw construct. For both of these fixation constructs, there are several technical considerations that one should be aware of. Many of these considerations have been the subject of recent studies on the management of these fractures.[28-32] The following paragraphs will address the use of these two fixation constructs and the technical considerations that are associated with them.

Plate and Screw Fixation

If plate fixation is chosen for surgical management of these fractures, there are several technical considerations, which include plate size, precontoured plate versus reconstruction plate, superior versus anterior-inferior plate, and single plate versus dual plates.

Plate Size

Most commonly, a 3.5-mm plate (ie, dynamic compression plate or reconstruction plate) is used for the fixation construct. Galdi et al[33] investigated whether a 2.7-mm plate could be used by comparing the results of a 2.7-mm plate versus a 3.5-mm plate. They found no difference in time to union, nonunion rates, or outcome scores at 1 year and had a decreased rate of implant removal compared with the 3.5-mm plate. Gilde et al[34] found an increased rate of implant failure, malunion, and nonunion when a 2.7-mm reconstruction plate was used. However, in those fractures treated with a 2.7-mm dynamic compression plate, the outcomes were good with low rates of failure and nonunion.

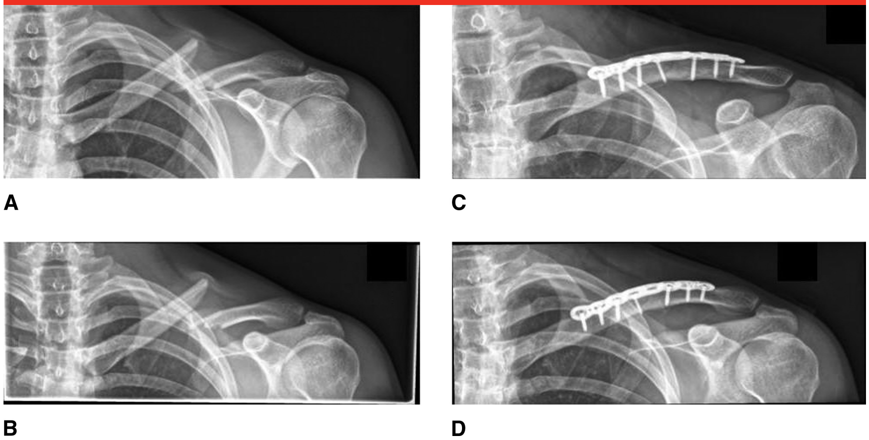
Precontoured Plates

Several studies have demonstrated advantages to precontoured plating systems, with similar biomechanical strength, decreased implant irritation, decreased implant removal, and improved cosmesis compared with reconstruction style plates.[35-37] Studies by Malhas et al[36] and Rongguang et al[35] found that even with the use of precontoured plates, there are higher rates of implant irritation and subsequent removal in female patients and patients with a lower body mass index. Malhas et al[36] recommended the use of systems that have more plate options because they result in a better contoured fit in most patients. As such, if superior plating is used, precontoured plating systems should be strongly considered.

Plate Position: Superior Versus Anterior-inferior

When performing plate and screw fixation for ORIF, the two common plate positions are superior and anterior-inferior. Several biomechanical studies have recently compared the strength of these two constructs.[38-43] A major advantage to superior plating is that for most fracture patterns, the plate is on the tension side of the fracture. Meanwhile, the major advantages of anterior-inferior plating are that longer screws can be placed, the screws can be directed away from vital structures, and the construct is rotationally stronger.[38-43] In one of these first studies, Iannotti et al[38] created midshaft clavicle fracture models with a transverse osteotomy. They found that a superior plating technique resulted in the strongest biomechanical construct and recommended superior plating for displaced midshaft fractures. Recent studies have found more mixed results. Several of these biomechanical studies have compared superior with anterior-inferior plating. The results of these studies are summarized in Table 2 (see Supplemental Digital Content 2, http://links.lww.com/JAAOS/A126).

Figure 1



Preoperative (**A**, **B**) and postoperative (**C**, **D**) radiographs of a 26-year-old man who sustained a displaced midshaft clavicle fracture that was treated with a superior precontoured plate construct with an interfragmentary lag screw. The patient had uneventful postoperative course and went onto union.

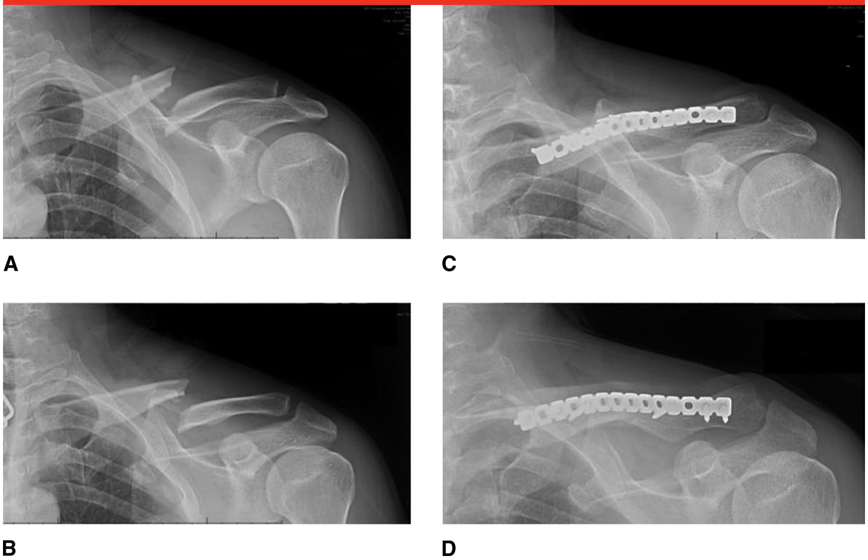
Toogood et al[41] and Pratal et al[43] used synthetic clavicles to compare the biomechanical strength of superior versus anterior-inferior plating. They ultimately found that anterior-inferior plates resisted cantilever bending best, which is in contrast to Celestre et al who found superior plating to be the best in resisting these forces.[40,41,43] Favre et al[42] performed a finite element analysis in which they found that anterior-inferior plating resulted in deformation that was similar to the intact clavicle and recommended anterior-inferior plating for all patients except those who would be returning to activities that had a higher risk of shoulder impact (Figures 1 and 2).

From a clinical standpoint, studies have focused on implant failure, removal, and irritation when comparing the two plating techniques. Sohn et al[44] performed an RCT comparing the techniques and found no differences in implant irritation, outcome scores, or time to union (16.8 versus 17.1 weeks). Hulsmans et al[45] found an equal rate of implant removal between the groups and no difference in implant-related irritation between the two techniques. Collinge et al[46] found a low rate of complications and symptomatic implant, along with excellent outcome scores in their series of 80 patients who underwent anterior-inferior plating. They concluded that fracture pattern should dictate the plate position. Independent of plate position, the surgeon can attempt to decrease implant irritation through a meticulous dissection that maintains a platysma fascial layer that can be closed over the plate at the end of the case.

Dual Plating

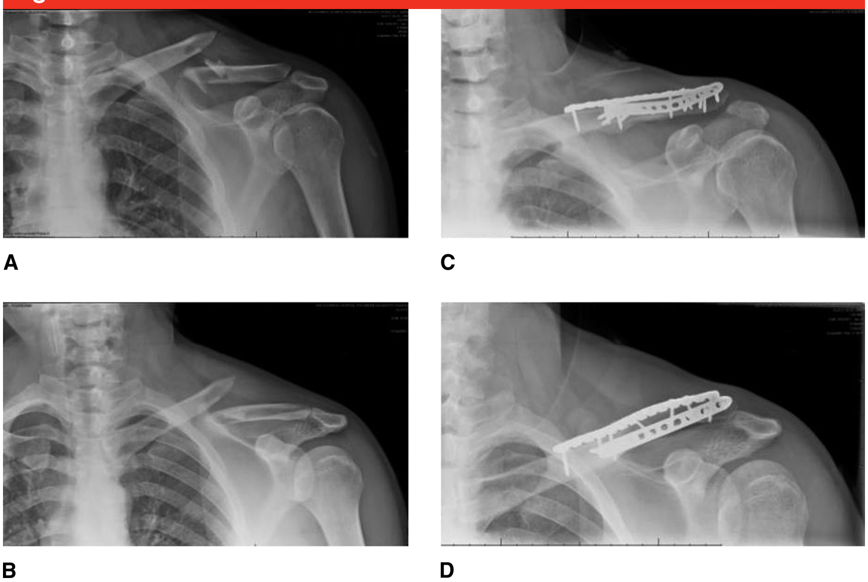
In recent years, dual plating for displaced midshaft clavicle fractures has attracted an increasing amount of attention in the literature. Most describe the use of a 2.7-mm or 3.5-mm reconstruction style plate placed anterior-inferior with a 2.0-mm or 2.4-mm mini-fragment style plate placed superior. This is thought to

Figure 2



Radiographs (**A**, **B**) of a 49-year-old right-hand-dominant man who sustained a comminuted left midshaft clavicle fracture. The patient underwent anterior-inferior plating (**C**, **D**) using a 2.7-mm reconstruction style plate and a 2.0-mm mini-fragment plate fixation for provisional reduction.

Figure 3



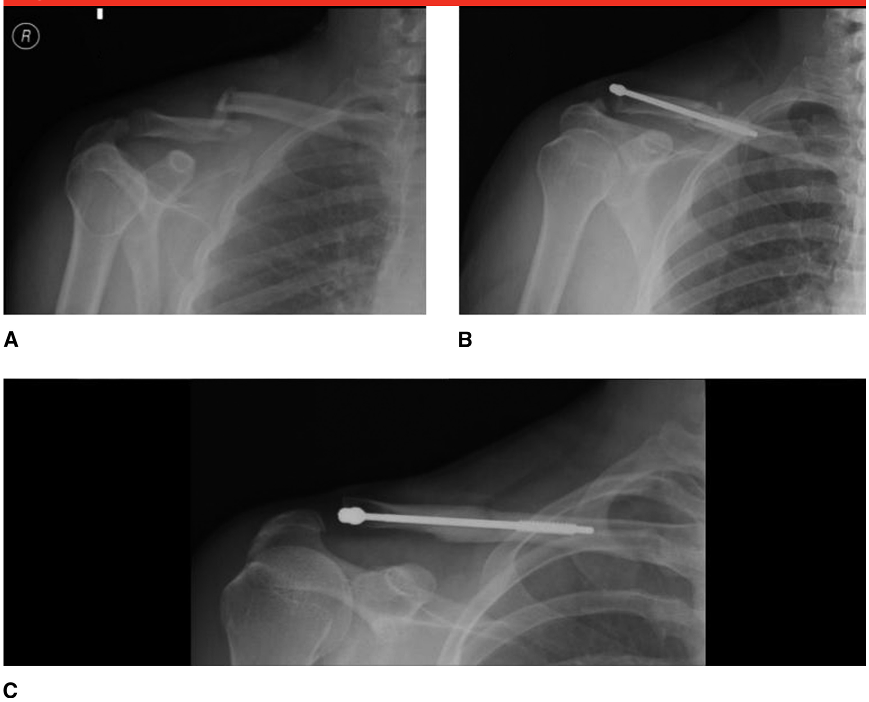
Radiographs (**A**, **B**) of a 43-year-old right-hand-dominant man who sustained a comminuted left midshaft clavicle fracture. The patient underwent dual plate fixation (**C**, **D**) using a superior 2.7-mm reconstruction style plate with a second anterior-inferior plate and 2.0-mm interfragmentary lag screw fixation.

create a stiffer construct and results in decreased implant irritation because smaller plates are used.[47-49] Prasan and colleagues reviewed a cohort of patients treated with dual plating. In addition, they performed a biomechanical study with synthetic clavicles comparing dual plating with superior and anterior-inferior plating. There were no nonunions, and union occurred at an average of 14.7 weeks with good to excellent outcome scores. In addition, they had no cases of implant removal or irritation at 1 year. In their biomechanical arm, no differences were noted between the techniques in resisting axial or torsional loads, but dual plating was better at resisting superior loads compared with superior plating, and dual plating was better at resisting anterior loads compared with anterior-inferior plating.[47] Chen et al[48] compared radiographic outcomes in patients treated with dual plating with patients treated with a single superior or anterior-inferior plate. They found 100% union in the dual plating group compared with 91% in the single plate group. Furthermore, at 1 year, there were no cases of implant removal or irritation in the dual plating group. The low rate of implant irritation was reproduced in a study by Czajka et al,[49] who found a 3.7% rate of implant irritation and removal in patients treated with dual plating. Although many options exist between plating techniques, surgeons should balance patient characteristics, activity levels, and surgeon comfort when choosing the optimal technique for each patient (Figure 3).

Intramedullary Nailing

If the decision is made to use an IMN for fixation, several technique options exist, depending on the nail design. A percutaneous approach can be used for some, with a 1-cm incision made 1 to 2 cm lateral to the sternoclavicular joint. The lower edge of the cortex can be opened with a 2.5-mm drill and widened as necessary with an awl. Before passing the IMN, reduction is obtained. Should closed reduction be unsuccessful, the next step is percutaneous reduction, followed by open reduction. The IMN should be passed across the fracture site and advanced to the lateral cortex, with the medial end cut just below the skin. Another option uses an open approach centered over the fracture site. Once the fracture site is identified and delivered into the surgical wound the medial fragment, and subsequently, the lateral fragment is drilled and tapped through the fracture ends. When drilling the lateral fragment, the drill is advanced through the posterolateral cortex at a point that is in line with the coracoid. The nail is inserted first into the lateral fragment, the fracture is reduced, and then it is advanced into the medial fragment. Typically, a nail between 2.0 and 3.5 mm is used, with the goal being an IMN that is 30% to 40% of the midshaft medullary diameter.[50] Most IMNs today are elastic titanium nails, but in the past, Hagie pins or Kirschner wires were used.[2,23,29,31,50,51] IMN removal and time of removal is variable between studies, but Mueller et al[50] advocated removing all IMNs at 6 months (Figure 4).

Figure 4



Preoperative (**A**) and postoperative (**B**, **C**) radiographs of a 28-year-old man who sustained a displaced midshaft clavicle fracture that was treated with an intramedullary nail (IMN). The patient had uneventful postoperative course without implant irritation and planned removal of the IMN at 6 months postoperatively.

The use of IMNs has the potential to be a minimally invasive procedure, and RCTs have shown them to be superior to nonsurgical management in the prevention of nonunion.[22,23] The major question in discussing an IMN for surgical management of midshaft clavicle fractures is as follows: how does it compare with ORIF using a plate and screw construct?

Plate and Screws Versus Intramedullary Nails

Several preclinical studies have compared the biomechanical strength of a plate and screw construct versus an IMN.[30-32] Both Zeng et al[30] and Ni et al[32] performed finite element analyses comparing plate and screws with flexible IMNs. Zeng et al[30] found that the IMN had the greatest displacement and implant stresses with axial loads and cantilever bending, but although the plate was better at resisting these forces and less likely to fail, the IMN lead to more physiologic stress distribution. This is in comparison to Ni et al,[32] who found that plate and screws provided an even stress distribution, and as such, they recommended plate and screw fixation over intramedullary nailing. Wilson et al[31] compared intramedullary nailing with superior plating and found that at physiologic loads, the superior plate was better at resisting torsional and axial loads than the IMN.

In clinical studies, both van der Meijden et al[28] and Andrade-Silva et al[29] performed RCTs comparing superior plating with intramedullary nailing. van der Meijden[28] found that the plate group had less disability at 6 months from surgery and that 74% of the IMN cases that started percutaneous had to be converted to open reduction. In addition, 31 patients in the IMN group and five patients in the plate group reported implant irritation that required removal. Interestingly, 10% of the IMN group was converted to the plate group because of inability to pass the nail into the lateral aspect of the fracture. Andrade-Silva et al[29] found no difference in time to union or complications, but 40% of the patients in the IMN group compared with 14% in the plate group reported implant irritation. Other studies have found similar results with comparable time to union, outcomes, and high rates of implant irritation with IMNs.[45,51] This is an important point with IMNs because it is standard for IMNs to be removed and as such result in a second surgery for the patient.

Postoperative Rehabilitation

Postoperative protocols differ from surgeon to surgeon and among the different studies. In general, patients are given a sling for comfort for the initial 7 to 10 days, followed by the institution of range of motion exercises that limit forward elevation to 90° for 2 to 6 weeks. At 6 weeks, if clinical and radiographic examinations show signs of healing, the patient is allowed to begin strengthening exercises with the resumption of weight bearing at 3 months. Patients are typically allowed to return to sport at 4 to 6 months, depending on how their rehabilitation has progressed. For patients who undergo intramedullary nailing, the nail is typically removed at 6 months and as such results in a second surgery. However, this is highly variable depending on both the type of activity and surgeon preference.

Complications

Both nonsurgical and surgical treatment have well-documented complications. Symptomatic nonunion and malunion of the clavicle are the two most common complications of nonsurgical management, with symptomatic nonunion occurring in 14% to 24% of patients.[1,19,21,26,27,52] With surgical management, common complications include supraclavicular numbness from iatrogenic injury to branches of the supraclavicular nerve, superficial and deep infection, implant irritation, revision surgery, and nonunion.[45,49,53,54] Leroux et al[53] examined the revision surgery risk of a cohort of 1,350 patients who had undergone ORIF with at least 2 years of follow-up. They found an overall 24.6% revision surgery rate, with low rates of nonunion (2.6%), malunion (1.1%), and infection (2.6%). In their study, the most common reason for revision surgery was implant irritation. They reported a lower rate of other less common complications such as pneumothorax (0.01%) and neurovascular injury (0.003%). When examining all patient demographics, they found an increased rate of complications in patients with increased comorbidities. Female patients had the highest risk of secondary surgery for implant removal because of implant irritation at an average time of 12 months from index surgery.

Naimark et al[54] reported similar findings with implant irritation. They had a 12.7% rate of implant removal for implant irritation and a 1% revision ORIF rate with female patients being four times as likely to undergo plate removal for symptomatic implant. Overall, the rate of implant irritation from any form of surgical fixation ranges from 3.7% to 40%, with the lowest rates of implant irritation and removal reported with dual plating techniques.[28,29,45,53,54]

Summary

There has been a notable amount of literature generated over the past decade on the optimal approach to treating displaced midshaft clavicle fractures in adults. We now know that the rate of nonunion with nonsurgical treatment is higher than previously thought. This knowledge does not mean that all patients with displaced midshaft clavicle fractures should have surgical fixation. Although a few studies have attempted to identify the patient who will go onto a symptomatic nonunion, this is an area of the literature that is markedly lacking. Thus, for patients with midshaft clavicle fractures that are shortened greater than 2 cm, displaced greater than 100%, are highly comminuted, or have a Z-type pattern, surgical intervention should be heavily considered. For cases in which surgical management is undertaken, the outcome results of plate and screw fixation versus intramedullary nailing are similar, and as such, surgeons should perform the procedure they are most adept and comfortable with. For female patients and patients with a low body mass index, either a precontoured plate or dual plating technique should be considered, although more prospective studies are still needed on dual plating to see whether it can perform superior to the other plating techniques while maintaining a low implant irritation rate and high union rate.

References

Evidence-based Medicine: In this article, references 1, 7, 18, 20-24, 26, 28, 29, 51 are level I studies. References 5, 15-17, 25, 44, 45 are level II studies. References 4, 6, 8, 10, 27, 33, 46, 48, 50, 52, 54 are level III studies. References 13, 14, 19, 34, 35, 47, 49, 53 are level IV studies. References 2, 3, 9, 11, 12, 30-32, 36, 37, 38-43 are level V expert opinion.

References in **bold type** are studies that have been published within the past 5 years.

1. Canadian Orthopaedic Trauma Society: Nonoperative treatment compared with plate fixation of displaced midshaft clavicular fractures: A multicenter, randomized clinical trial. *J Bone Joint Surg Am* 2007;89:1-10.
2. Rowe CR: An atlas of anatomy and treatment of midclavicular fractures. *Clin Orthop Rel Res* 1968;58:29-42.
3. Neer CS II: Nonunion of the clavicle. *J Am Med Assoc* 1960;172:1006-1011.
4. Hill JM, McGuire MH, Crosby LA: Closed treatment of displaced middle-third fractures of the clavicle gives poor results. *J Bone Joint Surg Br* 1997;79:537-539.
5. Nowak J, Holgersson M, Larsson S: Sequelae from clavicular fractures are common: A prospective study of 222 patients. *Acta Orthop* 2005;76:496-502.
6. McKee MD, Pedersen EM, Jones C, et al: Deficits following nonoperative treatment of displaced midshaft clavicular fractures. *J Bone Joint Surg Am* 2006;88:35-40.
7. McKee RC, Whelan DB, Schemitsch EH, McKee MD: Operative versus nonoperative care of displaced midshaft clavicular fractures: A meta-analysis of randomized

clinical trials. *J Bone Joint Surg Am* 2012; 94:675-684.

8. Austin LS, O'Brien MJ, Zmistowski B, et al: Additional x-ray views increase decision to treat clavicular fractures surgically. *J Shoulder Elbow Surg* 2012;21:1263-1268.
9. Eskola A, Vainionpaa S, Myllynen P, Patiala H, Rokkanen P: Outcome of clavicular fracture in 89 patients. *Arch Orthop Trauma Surg* 1986;105:337-338.
10. Chan KY, Jupiter JB, Leffert RD, Marti R: Clavicle malunion. *J Shoulder Elbow Surg* 1999;8:287-290.
11. **Shields E, Behrend C, Beiswenger T, et al: Scapular dyskinesis following displaced fractures of the middle clavicle. *J Shoulder Elbow Surg* 2015;24:e331-e336.**
12. Patel B, Gustafson PA, Jastifer J: The effect of clavicle malunion on shoulder biomechanics; a computational study. *Clin Biomech (Bristol, Avon)* 2012;27:436-442.
13. Matsumura N, Ikegami H, Nakamichi N, et al: Effect of shortening deformity of the clavicle on scapular kinematics: A cadaveric study. *Am J Sports Med* 2010;38: 1000-1006.
14. Ledger M, Leeks N, Ackland T, Wang A: Short malunions of the clavicle: An anatomic and functional study. *J Shoulder Elbow Surg* 2005;14:349-354.
15. Lazarides S, Zafiropoulos G: Conservative treatment of fractures at the middle third of the clavicle: The relevance of shortening and clinical outcome. *J Shoulder Elbow Surg* 2006;15:191-194.
16. Andersen K, Jensen PO, Lauritzen J: Treatment of clavicular fractures: Figure-of-eight bandage versus a simple sling. *Acta Orthop Scand* 1987;58:71-74.
17. **Ersen A, Atalar AC, Birisik F, Saglam Y, Demirhan M: Comparison of simple arm sling and figure of eight clavicular bandage for midshaft clavicular fractures: A randomised controlled study. *Bone Joint J* 2015;97-B:1562-1565.**
18. Robinson CM, Goudie EB, Murray IR, et al: Open reduction and plate fixation versus nonoperative treatment for displaced midshaft clavicular fractures: A multicenter, randomized, controlled trial. *J Bone Joint Surg Am* 2013;95:1576-1584.
19. **Fuglesang HF, Flugsrud GB, Randsborg PH, Stavem K, Utvag SE: Radiological and functional outcomes 2.7 years following conservatively treated completely displaced midshaft clavicle fractures. *Arch Orthop Trauma Surg* 2016;136:17-25.**
20. Virtanen KJ, Remes V, Pajarinen J, Savolainen V, Bjorkenheim JM, Paavola M: Sling compared with plate osteosynthesis for treatment of displaced midshaft clavicular fractures: A randomized clinical trial. *J Bone Joint Surg Am* 2012;94: 1546-1553.
21. **Woltz S, Stegeman SA, Krijnen P, et al: Plate fixation compared with nonoperative treatment for displaced midshaft clavicular fractures: A multicenter randomized controlled trial. *J Bone Joint Surg Am* 2017; 99:106-112.**
22. Smekal V, Irenberger A, Struve P, Wambacher M, Krappinger D, Kralinger FS: Elastic stable intramedullary nailing versus nonoperative treatment of displaced midshaft clavicular fractures—a randomized, controlled, clinical trial. *J Orthop Trauma* 2009;23:106-112.
23. Judd DB, Pallis MP, Smith E, Bottoni CR: Acute operative stabilization versus nonoperative management of clavicle fractures. *Am J Orthop* 2009;38:341-345.
24. **Devji T, Kleinlugtenbelt Y, Evaniew N, Ristevski B, Khoudigian S, Bhandari M: Operative versus nonoperative interventions for common fractures of the clavicle: A meta-analysis of randomized controlled trials. *CMAJ Open* 2015;3: E396-E405.**
25. **Xu J, Xu L, Xu W, Gu Y, Xu J: Operative versus nonoperative treatment in the management of midshaft clavicular fractures: A meta-analysis of randomized controlled trials. *J Shoulder Elbow Surg* 2014;23:173-181.**
26. Robinson CM, Court-Brown CM, McQueen MM, Wakefield AE: Estimating the risk of nonunion following nonoperative treatment of a clavicular fracture. *J Bone Joint Surg Am* 2004;86-A: 1359-1365.
27. Murray IR, Foster CJ, Eros A, Robinson CM: Risk factors for nonunion after nonoperative treatment of displaced midshaft fractures of the clavicle. *J Bone Joint Surg Am* 2013;95:1153-1158.
28. **van der Meijden OA, Houwert RM, Hulsmans M, et al: Operative treatment of dislocated midshaft clavicular fractures: plate or intramedullary nail fixation? A randomized controlled trial. *J Bone Joint Surg Am* 2015;97:613-619.**
29. **Andrade-Silva FB, Kojima KE, Joeris A, Santos Silva J, Mattar R Jr: Single, superiorly placed reconstruction plate compared with flexible intramedullary nailing for midshaft clavicular fractures: A prospective, randomized controlled trial. *J Bone Joint Surg Am* 2015;97:620-626.**
30. **Zeng L, Wei H, Liu Y, et al: Titanium elastic nail (ten) versus reconstruction plate repair of midshaft clavicular fractures: A finite element study. *PLoS One* 2015;10: e0126131.**
31. **Wilson DJ, Scully WF, Min KS, Harmon TA, Eichinger JK, Arrington ED: Biomechanical analysis of intramedullary vs. superior plate fixation of transverse midshaft clavicle fractures. *J Shoulder Elbow Surg* 2016;25: 949-953.**
32. **Ni M, Niu W, Wong DW, Zeng W, Mei J, Zhang M: Finite element analysis of locking plate and two types of intramedullary nails for treating mid-shaft clavicle fractures. *Injury* 2016;47:1618-1623.**
33. Galdi B, Yoon RS, Choung EW, et al: Anteroinferior 2.7-mm versus 3.5-mm plating for AO/OTA type B clavicle fractures: A comparative cohort clinical outcomes study. *J Orthop Trauma* 2013; 27:121-125.
34. **Gilde AK, Hoffmann MF, Sietsema DL, Jones CB: Functional outcomes of operative fixation of clavicle fractures in patients with floating shoulder girdle injuries. *J Orthop Traumatol* 2015;16:221-227.**
35. **Rongguang A, Zhen J, Jianhua Z, Jifei S, Xinhua J, Baoqing Y: Surgical treatment of displaced midshaft clavicle fractures: Precontoured plates versus noncontoured plates. *J Hand Surg Am* 2016;41: e263-e266.**
36. **Malhas AM, Skarparis YG, Sripada S, Soames RW, Jariwala AC: How well do contoured superior midshaft clavicle plates fit the clavicle? A cadaveric study. *J Shoulder Elbow Surg* 2016;25:954-959.**
37. **Van Tongel A, Huysmans T, Amit B, Sijbers J, Vanglabbeek F, De Wilde L: Evaluation of prominence of straight plates and precontoured clavicle plates using automated plate-to-bone alignment. *Acta Orthop Belg* 2014;80:301-308.**
38. Iannotti MR, Crosby LA, Stafford P, Grayson G, Goulet R: Effects of plate location and selection on the stability of midshaft clavicle osteotomies: A biomechanical study. *J Shoulder Elbow Surg* 2002;11:457-462.
39. **Chen Y, Yang Y, Ma X, et al: A biomechanical comparison of four different fixation methods for midshaft clavicle fractures. *Proc Inst Mech Eng H* 2016;230: 13-19.**
40. Celestre P, Roberston C, Mahar A, Oka R, Meunier M, Schwartz A: Biomechanical evaluation of clavicle fracture plating techniques: Does a locking plate provide improved stability? *J Orthop Trauma* 2008;22:241-247.
41. **Toogood P, Coughlin D, Rodriguez D, Lotz J, Feeley B: A biomechanical comparison of superior and anterior positioning of precontoured plates for midshaft clavicle fractures. *Am J Orthop* 2014;43:E226-E231.**
42. Favre P, Kloen P, Helfet DL, Werner CM: Superior versus anteroinferior plating of the clavicle: A finite element study. *J Orthop Trauma* 2011;25:661-665.
43. Partal G, Meyers KN, Sama N, et al: Superior versus anteroinferior plating of the clavicle revisited: A mechanical study. *J Orthop Trauma* 2010;24:420-425.
44. **Sohn HS, Shon MS, Lee KH, Song SJ: Clinical comparison of two different plating methods in minimally invasive plate**

osteosynthesis for clavicular midshaft fractures: A randomized controlled trial. *Injury* 2015;46:2230-2238.

45. Hulsmans MH, van Heijl M, Houwert RM, et al: High irritation and removal rates after plate or nail fixation in patients with displaced midshaft clavicle fractures. *Clin Orthop Rel Res* 2017;475: 532-539.

46. Collinge C, Devinney S, Herscovici D, DiPasquale T, Sanders R: Anterior-inferior plate fixation of middle-third fractures and nonunions of the clavicle. *J Orthop Trauma* 2006;20:680-686.

47. Prasarn ML, Meyers KN, Wilkin G, et al: Dual mini-fragment plating for midshaft clavicle fractures: A clinical and biomechanical investigation. *Arch Orthop Trauma Surg* 2015;135: 1655-1662.

48. Chen X, Shannon SF, Torchia M, Schoch B: Radiographic outcomes of single versus dual plate fixation of acute mid-shaft clavicle fractures. *Arch Orthop Trauma Surg* 2017;137:749-754.

49. Czajka CM, Kay A, Gary JL, et al: Symptomatic implant removal following dual mini-fragment plating for clavicular shaft fractures. *J Orthop Trauma* 2017;31: 236-240.

50. Mueller M, Rangger C, Striepens N, Burger C: Minimally invasive intramedullary nailing of midshaft clavicular fractures using titanium elastic nails. *J Trauma* 2008; 64:1528-1534.

51. Houwert RM, Smeeing DP, Ahmed Ali U, Hietbrink F, Kruyt MC, van der Meijden OA: Plate fixation or intramedullary fixation for midshaft clavicle fractures: A systematic review and meta-analysis of randomized controlled trials and observational studies. *J Shoulder Elbow Surg* 2016;25:1195-1203.

52. McKnight B, Heckmann N, Hill JR, et al: Surgical management of midshaft clavicle nonunions is associated with a higher rate of short-term complications compared with acute fractures. *J Shoulder Elbow Surg* 2016;25:1412-1417.

53. Leroux T, Wasserstein D, Henry P, et al: Rate of and risk factors for reoperations after open reduction and internal fixation of midshaft clavicle fractures: A population-based study in Ontario, Canada. *J Bone Joint Surg Am* 2014;96:1119-1125.

54. Naimark M, Dufka FL, Han R, et al: Plate fixation of midshaft clavicular fractures: Patient-reported outcomes and hardware-related complications. *J Shoulder Elbow Surg* 2016;25:739-746.