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Operative management of clavicular malunion in midshaft clavicular fractures: a report of 59 cases

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Background: Nonoperative management has long been the preferred treatment for clavicular fractures; however, good outcomes, particularly with a shortened and malunited clavicle, are not universal. We report on radiographic and patient-based outcomes of a patient cohort with symptomatic clavicular malunions managed with corrective osteotomy, plate fixation, and local bone graft. We hypothesized that local bone graft would be sufficient for achieving union and length of malunion time would not affect the outcome.

Method: Over a 10-year period, 59 cases underwent operative management of symptomatic clavicular malunion. The surgical technique included osteotomy of the malunion, restoration of length, fixation with a plate, and local bone graft. The average length of time between fracture and surgery was 193.42 weeks (range, 8 weeks to 30 years). All patients were followed up postoperatively until radiographic union was achieved. Disabilities of the Arm, Shoulder and Hand scores were obtained and patients completed questionnaires to assess patient-based outcomes postoperatively.

Results: All 59 cases achieved union with an average time of 9.25 weeks (range, 6-38 weeks) and only required local bone graft. All patients improved postoperatively with a mean Disabilities of the Arm, Shoulder and Hand score of 1.81 (range, 0-20.68) at 12 months. In 2 patients, infection developed, requiring revision of fixation, and union was subsequently achieved. Two patients had fractures adjacent to their hardware after union was achieved.

Conclusions: Corrective osteotomy with restoration of length and alignment, soft-tissue preservation, local bone graft, and plate fixation is a reliable treatment option for midshaft clavicular malunion. Union can be achieved, with good clinical outcomes independent of malunion time.

Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Clavicle; malunion; shoulder; fracture; osteotomy; bone graft

Approximately 2% to 5% of adult trauma results in fractures of the clavicle. Midshaft clavicular fractures are the most common (>66%). A displaced midshaft clavicular fracture will heal with a degree of shortening and rotation if managed nonoperatively and radiographic malunion is expected. Nonoperative management has long been the

The Adventist HealthCare Limited Human Research Ethics Committee (HREC) approved this study (HREC Project ID 2013-018).

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Clavicle Malunion Corrective osteotomy post-operative questionnaire.

Clavicle Questionnaire

Patient:	Operation Date:

Date of post op visit:			
How long did you wear the sling for?			
Have you returned to work?			
Have you returned to sports?			
Does your shoulder feel normal?			
When did you achieve full range of motion?			
Would you have the operation again?			
What size is the scar?			
Time to union?			

Figure 1 Clavicle questionnaire. *post op*, postoperatively.

preferred treatment for clavicular fractures; however, good outcomes are not universal.[23]

Recent studies examining patient-based outcomes (eg, the Disabilities of the Arm, Shoulder and Hand [DASH] score) have shown that nonoperative management resulted in patient dissatisfaction. McKee et al[12] examined the outcomes of 105 polytrauma patients with clavicular fractures, reporting a mean DASH score of 32 points, representing significant impairment. Hill et al[6] assessed 52 patients with an outcome questionnaire after nonoperative management of midshaft clavicular fractures. Of these patients, 31% reported unsatisfactory results with complications such as irritation of the brachial plexus, cosmetic deformity, and residual pain. McKee et al[11] later reported on patient-based outcomes and the shoulder strength of 30 patients with midshaft clavicular fractures managed nonoperatively. They reported a significant level of residual disability, with a mean DASH score of 24.6 points, and detected residual deficits in shoulder strength. In 2017, Woltz et al[24] reported on 6 randomized controlled trials suggesting that plate fixation reduced the risk of nonunion and that patients improved in terms of DASH and Constant scores after 1 year. However, a more recent meta-analysis of 9 randomized controlled trials by Ahmed et al[1] has suggested that operative fixation leads to better early functional outcomes and DASH scores but that there is no significant difference compared with nonoperative management at 12 months after injury. Patients with symptomatic clavicular malunions have been the focus of recent studies (McKee et al[14] and Hillen and Eygendaal[7]) assessing the surgical outcomes of corrective osteotomies.

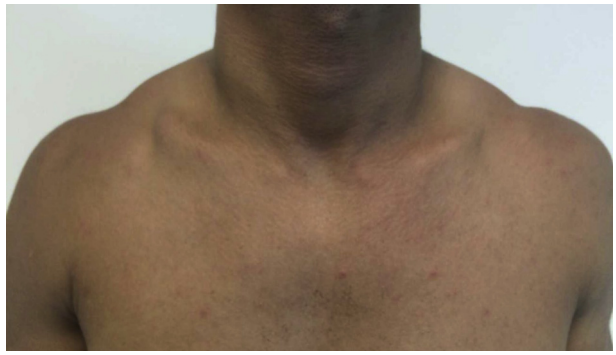

Figure 2 Example case 1 preoperatively.

We report on the radiographic and patient-based outcomes of a large cohort of patients with symptomatic clavicular malunions managed with corrective osteotomy, plate fixation, and local bone graft. We hypothesized that local bone graft would be sufficient for achieving union rather than iliac crest bone graft and that the length of malunion time would not affect the final outcome.

Materials and methods

We analyzed the database of a senior surgeon to identify 59 malunited clavicles in 58 patients who underwent operative management of symptomatic malunion of a midshaft clavicular fracture from November 2005 to October 2016. Symptomatic patients were defined as those who experienced ongoing discomfort, pain, or impaired function secondary to a healed, closed, displaced midshaft clavicular fracture at least 8 weeks after the injury. Patients had a range of complaints including scapular prominence, pain at the rotator cuff muscles, cosmetic deformity, a sensation of the shoulder sitting forward, and difficulty with clothing (eg, a bra strap falling down). The most common complaint noted by patients in this cohort was that the shoulder ''did not feel right.''

All patients were followed up until union was achieved clinically and radiographically. DASH scores were collected preoperatively for 16 of 59 cases. This low number resulted from preoperative DASH score collection only having been started in 2015. DASH scores were collected postoperatively for 55 of 59 cases. The mean DASH score in the preoperative group was compared with the mean DASH score in the 1-year postoperative group using an unpaired *t* test. A separate questionnaire as shown in Figure 1 was completed by all patients postoperatively to assess patient-based outcomes. This included scar paresthesia, plate irritation, return to work, return to sport, range of motion, and scar size. Patients were also asked whether their shoulder ''felt normal'' and whether they would undergo the operation again.

Patients were categorized into various periods of malunion after injury (8-26 weeks, 26 weeks to 1 year, 1-2 years, or >2 years). The mean DASH scores of patients in these groups 1 year postoperatively were compared with a 1-way analysis of variance test.

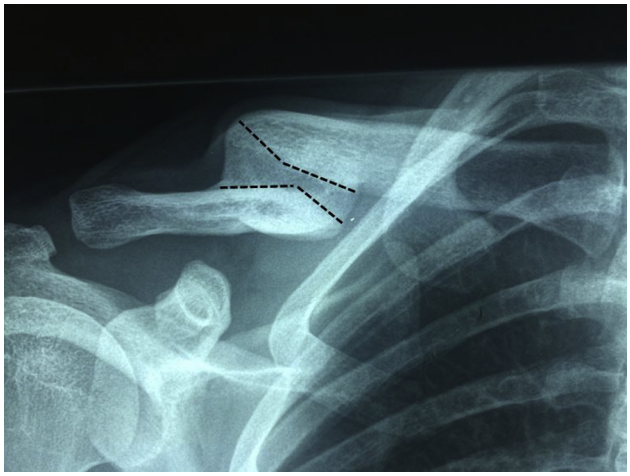

Figure 3 Preoperative planning for osteotomy in example case 1. *Dashed lines* indicate osteotomy cut.

Operative technique

Prior to surgery, each patient is assessed clinically and radiologically to determine the degree of shortening of the clavicle and the site of the malunion. Measurements are made comparing the contralateral clavicle with the affected clavicle. The degree of shortening is measured both clinically and radiologically using a comparison radiograph and 3-dimensional (3D) computed tomography (CT) scan. From the comparison views, one can then determine how much length we aim to restore to the clavicle and at what level and plane the osteotomy needs to be performed. We aim for a transverse osteotomy in some instances and an oblique osteotomy in other cases depending on the original fracture pattern. The overall aim is to try to re-create the normal anatomy of the clavicle and to restore overall length. In certain circumstances, shortening of a few millimeters can be accepted as long as the clavicle becomes straight and the bone ends are opposed. Figures 2-4 demonstrate clinical and radiographic planning.

All planning and operations were performed by the senior surgeon, with the patient in the beach-chair position on a standard operating table that is radiolucent. The arm remained free in a sterile stockinet, and the upper arm, shoulder, neck, and ipsilateral torso were prepared and draped.

A small, 3- to 5-cm incision is made centered at the location of the malunion of the clavicle and just inferior to the subcutaneous surface of the clavicle. The incision is inferior to make sure there is no irritation from the scar over the plate once the fracture has

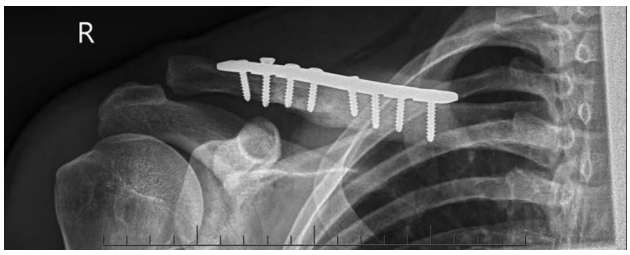

Figure 4 Example case 1 at 14 weeks postoperatively.

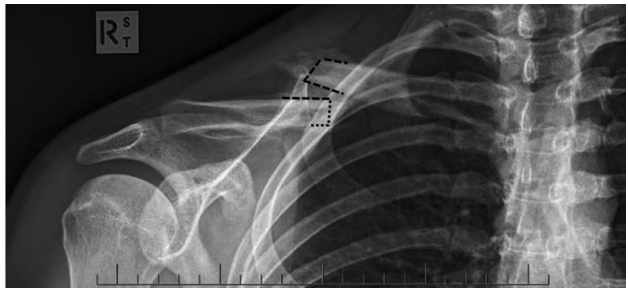

Figure 5 Preoperative radiograph in example case 4. *Dashed lines* indicate osteotomy cut.

healed. Superior dissection is then made to identify the site of malunion; in doing this, an attempt is made to protect the sensory supraclavicular nerves. Hohmann retractors are placed over and around the clavicular malunion site, and the bony deformity is isolated. The periosteum overlying the malunion site and the clavicular shafts that will host the plate are elevated.

Once the site of malunion is exposed, preoperative planning is used to determine the type of osteotomy. Often, hypertrophic callous must be removed to expose the true bone ends and the shafts of the clavicle around the malunion site. Any extra bone from the osteotomy site is then kept for potential graft at the end of the procedure. An osteotome is used to re-create the original fracture pattern in either an oblique or transverse pattern as seen in Figures 5 and 6. This has often been decided using radiographs and 3D CT scans that have been compared with the contralateral side prior to surgery. This can be seen in Figures 7-9, in which CT imaging demonstrates shortening of 1.5 cm. The medullary canal is then re-established, and bleeding bone is achieved at each of the fracture ends. Any rotational deformity is also corrected and can be determined by looking at the normal superior aspect of the medial and lateral fragments and realigning in this plane. Clavicle length is maintained by re-creating the original fracture pattern and realigning the ends of the bones in their anatomic position. This has become easier to do with the new anatomic precontoured plates. In certain cases, a degree of shortening of up to 5 mm can be accepted as long as the bone ends are opposed and the clavicle is flat and straight. In none of these cases was iliac crest graft necessary. In all cases, the bone ends easily compressed to each other as they had previously been in a shortened position and naturally wanted to compress back to each other. It is important to have 3 bicortical screws with good fixation to the distal cortex through the plate on either side of the fracture. Once solid fixation had been achieved, an image intensifier is used to check alignment, length, and anatomic fixation. The surgical site undergoes

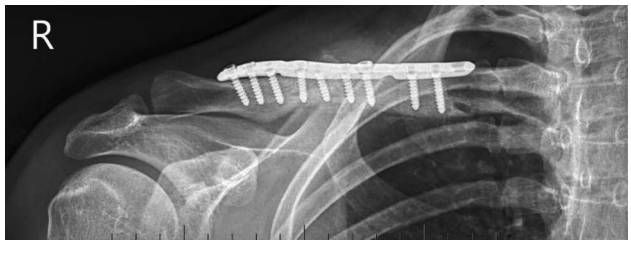

Figure 6 Postoperative radiograph in example case 4.

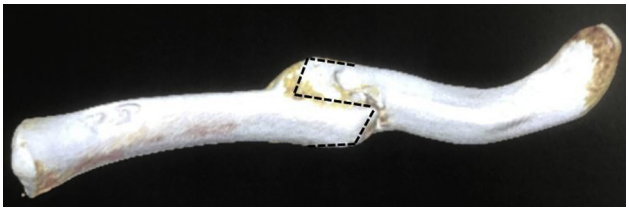

Figure 7 Preoperative computed tomography in example case 2. *Dashed lines* indicate osteotomy cut.

lavage, and the local bone from the osteotomy site is packed in and around the site of malunion. The wound is closed and dressed. Postoperative radiographs are also taken to assess fixation. Length is restored either to normal or within 5 mm of the contralateral side.

Patients are placed into a shoulder immobilizer for 1 to 2 weeks and are allowed to gradually move their arm as comfort allows over the next 4 weeks. Full active range of motion is usually gained by 4 to 6 weeks, and return to normal unrestricted activity is allowed once the bone has healed clinically and radiologically. Regular follow-up was performed until union was achieved.

Results

There were 50 male and 8 female patients with a mean age of 29.8 years (range, 12-58 years). There were 24 right-sided and 35 left-sided clavicular malunions. This study included 1 patient with bilateral clavicular malunion. The mean time from the initial injury to surgery was 193.42 weeks (range, 8 weeks to 30 years). Of these 59 cases, 21 (35.6%) received surgery more than 1 year after the initial injury.

The average period of follow-up postoperatively was 190.64 weeks (range, 12-520 weeks). All patients achieved bony union postoperatively. The average time to bony union was 9.25 weeks (range, 6-38 weeks).

Of the patients, 55 (95%) returned completed DASH scores at 1 year postoperatively. The mean postoperative DASH score was 1.85 (range, 0-20.68), which demonstrated a significant improvement on the mean preoperative DASH score of 26.32 (range, 14.16-47.5). By use of an unpaired *t* test, a significant difference in means was shown

Figure 8 Preoperative computed tomography bilaterally in example case 2. *Dashed lines* indicates length.

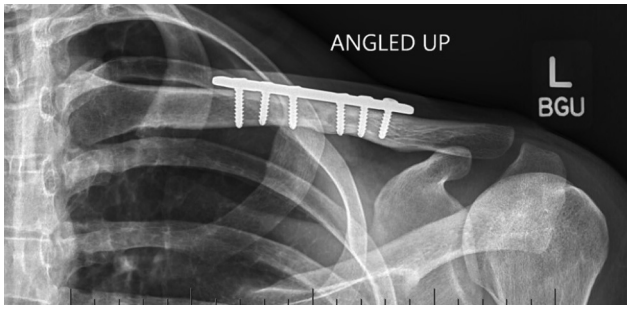

Figure 9 Example case 2 at 4 months postoperatively.

($P < .0001$). The mean 1-year postoperative DASH score of the 16 patients who provided preoperative DASH scores was 3.04. Of these patients, 15 provided follow-up DASH scores at 1 year, and this improvement was also deemed significant ($P < .0001$). Scar length was measured in 36 patients in the cohort, with an average length of 4.9 cm (range, 3-8 cm). Plates were removed in 17 cases in the cohort. The senior surgeon's protocol was to remove clavicular plates in adolescent patients. This included removal of plates in 8 patients younger than 19 years. The remaining 9 patients underwent plate removal for local irritation. A total of 36 patients were assessed for sensation changes surrounding the operative site; 14 patients (39%) experienced mildly reduced sensation around the scar.

Within the 58-patient cohort, 36 patients responded to the postoperative questionnaire and demonstrated a high rate of satisfaction as shown in Table I. All patients reported that they had returned to their preinjury level of function when questioned about sporting, work, and leisure activities. All patients returned to work at an average of 3 weeks postoperatively (range, 1-12 weeks). In addition, patients returned to sporting activities at an average of 10 weeks postoperatively (range, 6-16 weeks). Full range of motion was achieved by all patients at an average of 8 weeks postoperatively (range, 2-24 weeks). Patients

Table I Clinical outcomes after osteotomy

Clinical outcome	Data
Average time to return to work (range), weeks	3 (1-12)
Average time to return to sport (range), weeks	10 (6-16)
Average time to return to full range of motion (range), weeks	8 (2-24)
Average time to union (range), weeks	9 (6-38)
Average scar size (range)	4.9 (3-8)
Average sling duration (range), weeks	2 (1-3)
Patient would undergo operation again	100%

Table II Variation in mean DASH scores 1 year postoperatively for clavicular malunions undergoing osteotomy at different periods after injury

Time of malunion	No. of clavicles	Mean DASH score
8 to 26 weeks	33	1.43
26 weeks to 1 yr	4	1.67
1-2 yr	6	3.52
>2 yr	16	2.11

DASH, Disabilities of the Arm, Shoulder and Hand.

reported use of a sling for an average of 2 weeks (range, 1-6 weeks). All patients reported that they would undergo the operation again if faced with a similar scenario. Cosmetically, there was a high rate of patient satisfaction with improvement in shoulder symmetry. Pain and discomfort were also markedly decreased.

The difference in mean DASH scores of patients in groups at varying periods after their initial injury is demonstrated in Table II. A 1-way analysis of variance test was used to analyze the difference in means and demonstrated no statistical significance ($P = .847$).

Two patients who achieved union returned to sport and sustained fractures adjacent to the plate. They both required revision fixation. Two patients had a deep infection requiring wound débridement, removal of hardware, and revision fixation and subsequently went on to achieve union. One patient had poor fixation when radiographs were taken at the first postoperative visit. The images showed a gap at the osteotomy site. The senior surgeon was not happy with the fixation and was concerned it would fail. The patient therefore returned to the operating theater, the fixation was revised, and the gap was closed, creating a much more solid and stable fixation. This patient subsequently went on to an uneventful recovery and bony union.

Figures 10 and 11 are radiographic images of the patient in our cohort with the longest period of malunion prior to osteotomy and fixation. This was a 46-year-old male patient who presented with malunion 30 years after initial clavicular fracture at age 16 years. He had a subsequent injury, resulting in re-fracture through the malunion site. Over the past 30 years, he had complained of ongoing discomfort and had been reviewed by previous surgeons but had never been offered a corrective osteotomy because they were concerned about complications associated with the operation. He underwent osteotomy and plate fixation 6 weeks after injury for ongoing deformity and pain. Six months postoperatively, he reported excellent function, full range of motion, and no pain. He stated his shoulder now "feels normal."

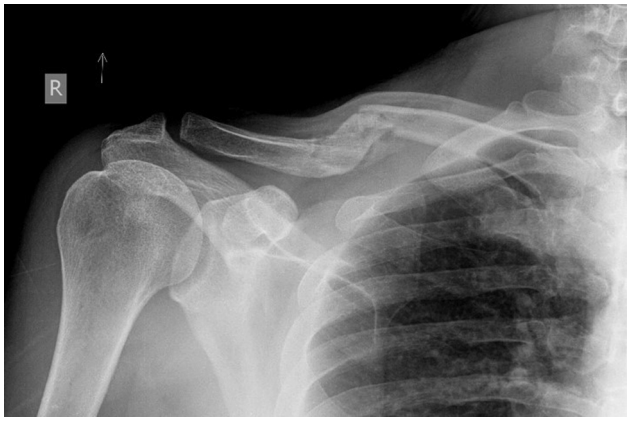

Figure 10 Example case 3 preoperatively.

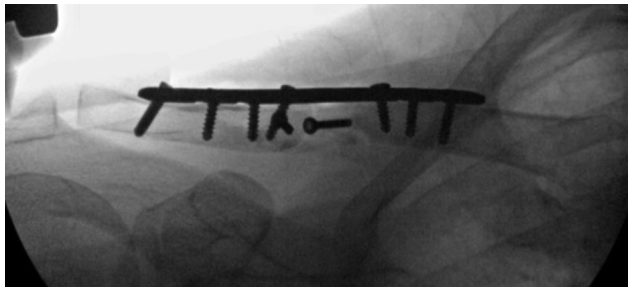

Figure 11 Example case 3 postoperatively.

Discussion

When managed nonoperatively, midshaft clavicular fractures commonly heal with a degree of malunion. It has generally been accepted that this malalignment rarely causes a functional problem. Historically, this was driven by the large studies of Neer[15] in 1960 and Rowe[19] in 1968 with nonunion rates of less than 1%. Recent studies focusing on patient-based outcomes rather than radiographic outcomes have demonstrated that not all patients with a malunion achieve optimal shoulder function.[4,5,11,16] McKee et al[11] in 2006 showed that patients with displaced clavicular fractures managed nonoperatively had reduced strength and increased DASH scores indicating substantial residual disability. Patel et al[17] in 2012 conducted a computational study using a 3D model and concluded that clavicular malunion and shortening reduce the force-generating capacity of the shoulder, leading to functional deficit.

One of the first published prospective studies, in 2007, of 2 randomized cohorts comparing plate fixation with nonoperative management of displaced midshaft clavicular fractures demonstrated a symptomatic malunion rate of 18.4% in the nonoperative group compared with 0% in the operative group.[3] A follow-up meta-analysis of 6 RCTs in 2012 by McKee et al[13] reinforced this finding, demonstrating a 9% rate of symptomatic malunion in the nonoperative group vs. 0% in the operative group. These studies used patient-based outcomes and DASH scores to demonstrate that radiographic union alone does not guarantee treatment success.

In a more recent study, Kumar and Gulati[9] in 2018 reported on 40 patients with displaced midshaft clavicular fractures managed operatively and 40 patients managed nonoperatively in a randomized controlled trial. They demonstrated that operative fixation yielded better results in terms of union, functional outcome, and cosmetic appearance. In addition, a recent meta-analysis from Ahmed et al[1] reported on randomized controlled trials comparing plate fixation of displaced midshaft clavicular fractures and nonoperative management. They concluded that operative fixation resulted in a lower rate of nonunion (1.7% compared with 14.5%) and better early functional outcomes but found no significant difference in the long term (>12 months).

The aim of operative management of clavicular malunion is to restore the clavicular anatomy and provide an environment that supports bony union.[10] The currently available literature for operative management of clavicular malunion includes only case series and reports, with no level I or II evidence available. Sidler-Maier et al[22] published a literature review in 2017 that reported that all surgical techniques used for management of symptomatic clavicular malunions have resulted in good clinical outcomes with low complication rates. Among the 103 patients across 29 studies identified in the literature, the preferred method was corrective osteotomy, followed by fixation, seen in 77 patients. Fixation included plate fixation in 53 cases or intramedullary nailing in 6 cases. Bone graft was used in 32 patients and confirmed to be local autograft in 2 cases only.[22]

In our series, we did not find a need for iliac crest bone graft in any case and we found that local graft was sufficient. In all cases, there was excess bone at the osteotomy site that was kept and packed into the fracture site to stimulate healing. In 2017, Beirer et al[2] assessed the use of iliac crest graft for the management of both nonunion and malunion (n = 11 and n = 3, respectively). Despite achieving union and good clinical outcomes, they reported on 2 secondary fractures of the anterior superior iliac spine secondary to iliac crest graft harvest. Our study suggests that for the management of malunion, there is no need for iliac crest bone graft, which carries risks in the form of increased operative time, blood loss, infection, hematoma, pain, fracture, sensory loss, and hypertrophic scar.[4]

Our study suggests that the proposed method of osteotomy, plate fixation, and local bone graft is sufficient for management of clavicular malunion. It has been suggested by Iannotti et al[8] that superior clavicle plate placement, as in our approach, provides a more rigid construct compared with other variations. Our surgical technique uses a small inferior incision, which results in a cosmetically appealing scar and reduces the rate of postoperative skin irritation, owing to the incision being below the plate. Depending on fracture orientation, the limited incision is typically 4 to 5 cm in length; as such, there is a lower incidence of paresthesia. Regardless of operative technique, the documented complications after clavicular fixation include nonunion (0%-13%), loss of fixation (0%-10%), painful implant prominence, and skin problems overlying the plate.[21] Furthermore, vital anatomic structures in close proximity to the clavicle are at risk with some of these methods.[20]

The literature review conducted by Sidler-Maier et al[22] reported the time between injury and corrective osteotomy for clavicular malunion varied enormously from 4 weeks to 22 years. A large proportion of our study population underwent operative management greater than 1 year after their fracture (range, 8 weeks to 30 years). On the basis of our series, the length of malunion time after injury did not affect the rate of achieving union. However, Potter et al[18] compared acute repairs vs. delayed reconstruction for displaced clavicular fractures including malunions and showed that early repairs had improved clinical outcomes. This may encourage early correction of clavicular malunion owing to easier restoration of anatomy and less soft-tissue and bony dissection.

In the largest individual study currently in the literature, McKee et al[14] in 2003 assessed the clinical and radiographic outcomes of 15 patients who underwent corrective osteotomy for midshaft clavicular malunion. All patients except 1 achieved union, and all patients demonstrated improved clinical outcomes and DASH scores. Similarly to our study, McKee et al described an operative technique involving osteotomy, correction of alignment, and application of a superior clavicle plate. In the second largest cohort, comprising 10 patients, reviewed by Hillen and Eygendaal[7] in 2007, corrective osteotomy and superior plating were also described. Bony union was demonstrated in all patients except 1, with improvement of DASH scores.

Our study of 59 cases is the largest known cohort in the literature. Our population postoperatively showed improved range of movement and a reduction in pain and reported the feeling that the shoulder function had returned to ''normal'' or as it was before fracture. Strengths of this study include a large degree of participation in the assessment of postoperative patient-based outcome measures and DASH scores. Limitations include the study's retrospective nature and lack of preoperative assessments; however, over the past 3 years, collection of preoperative DASH scores has been initiated and will contribute to future research.

Conclusion

We propose a surgical management option for patients who have unsatisfactory results in the form of symptomatic malunion from nonoperative management of midshaft clavicular fractures. We demonstrate through patient-based outcomes that corrective osteotomy for midshaft clavicular malunion, including restoration of length and alignment, soft-tissue preservation, use of local bone graft, and plate fixation, is a reliable treatment option, regardless of the time since fracture.

Disclaimer

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