Clavicle Malunions: Surgical Treatment and Outcome—a Literature Review

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Abstract *Background:* Successful treatment of clavicle malunion represents a major challenge for orthopedic surgeons. *Questions/Purposes:* The aim of this study was to provide an overview of surgical options for the treatment of clavicle malunions regarding their technical details and clinical results. *Methods:* A comprehensive search of the literature was performed to retrieve articles and conference abstracts regarding the surgical treatment of clavicle malunions. A total of 1873 records were identified and 29 studies were included in the present review, with a total of 103 patients. *Results:* The majority of the patients (77/103) were treated with an osteotomy and subsequent open reduction internal fixation (ORIF). The next most frequent management choice was debridement, excision,

or removal of excess callus or bone ($n = 19$), but other techniques like resection of the clavicle ($n = 5$) or nerve exploration and decompression ($n = 2$) were also reported. The preferred method of fixation was plate fixation ($n = 53$) followed by pin fixation ($n = 6$). The complication rate was low, reported in less than 6% of patients. *Conclusion:* All of the currently reported surgical techniques to manage symptomatic clavicle malunion have resulted in good clinical outcomes with a low complication rate. Considering biomechanical aspects, correction osteotomy followed by plate fixation seems to be the preferred method. Further studies are needed to compare the various surgical techniques and their specific outcomes in a prospective manner. Nevertheless, this review article can be used as an overview to help choose an optimal operative treatment for patients presenting with a clavicle malunion.

Level of Evidence: Level IV: Systematic Review

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Introduction

Successful treatment of clavicular malunion represents a major challenge for orthopedic surgeons, in part because of the technical difficulty of securing adequate skeletal stabilization and also because of the unique anatomic features of the clavicle [32]. Several reports on the operative treatment of malunited clavicular fractures have been published, and the available literature suggests that, in general, bony union as well as restoration of the length and anatomy of the clavicle can be reliably achieved through surgical management of clavicle malunions [13–18].

Nevertheless, the different operative treatment options have not yet been systematically compared regarding their technical characteristics and clinical results. Therefore, the aim of this study was to review not only indications and

timing of surgery, but especially the different surgical techniques (e.g., for specific clinical situations) including the role of bone graft and methods of fixation, and to present the reported results of these different techniques.

Methods

A comprehensive search of the databases Medline, Biosis, CINAHL, Cochrane, Web of Science, Scopus, and Embase was performed to retrieve articles and conference abstracts published, and an additional hand search was performed using cross references and trial registers (<https://clinicaltrials.gov/> and <http://www.isrctn.com/>) were searched for current studies on “clavicle malunion.” The full search strategy for the MEDLINE search can be found in the “Supplementary Material.”

Studies were included if they described the surgical treatment of clavicle malunion. Original articles and case reports were included, if they detailed treatment of isolated clavicular malunion in adult patients (defined as 16 years or older [21]). Studies describing malunions after pathologic fractures were excluded. Furthermore, articles in languages other than English, French, and German that did not provide an abstract in English language were excluded. After the initial search was performed, the title and abstracts of all citations and retrieved studies were screened by 2 of the authors (CCS, NJD) for inclusion with use of the above criteria. Any discrepancies in inclusion decision were resolved by consensus. The full texts of articles that met the inclusion criteria were thoroughly reviewed according to the initial eligibility criteria.

The initial search retrieved 1870 records and after removal of duplicates, 1787 citations were screened (Fig. 1). Overall, 29 studies were included in the qualitative synthesis, including 1 conference abstract, 13 case reports, 10 case series, 1 cohort study, and 4 surgical technique papers reporting about patients treated surgically for their clavicle malunion (Table 1) reflecting 1 study with a level of evidence 2b [17], 24 studies with level 4, [1–11, 13, 15, 16, 19, 22, 24, 25, 28–31, 34, 35], and 4 studies with level 5 [20, 27, 33, 36] evidence.

Four papers [21, 27, 28, 36] represented updated reports or follow-up studies of the same patient cohort reported elsewhere (these are mentioned below the initial paper in Tables 1 and 2) leaving 25 studies for data extraction including a total of 103 patients.

Results

Patients

The age of the 103 patients ranged from 16 to 60 years. Fifty-eight patients had initially been treated nonoperatively, 15 have initially had an open reduction and internal fixation (ORIF) [17], and in 30 cases this detail was not reported (Table 1). The location of the malunion was the middle third in 70 cases, the lateral clavicle in 3, and in 30 patients the fracture location was not specified. In the majority of the

cases, the malunion criteria were deformity, displacement, malrotation (applied to 51 patients), and shortening (44 cases). Excessive callus formation was seen in 17 patients and in 41 patients, the authors did not specify. Reported clavicular shortening, though mostly not reported, was on average 2.1 cm, ranging from 0.9 to 4 cm (Table 1).

Indications and Timing of Surgery

The reported indications (some patients had more than one) for corrective osteotomy were functional limitation ($n = 19$ patients), shortening ($n = 44$), cosmetic dissatisfaction ($n = 17$), thoracic outlet syndrome ($n = 15$), unspecified neurological symptoms ($n = 13$), pain ($n = 10$, of which $n = 6$ night pain), and brachial plexus compression ($n = 8$). In 32 studies, operative indications were described with generic terms such as “symptomatic malunion” ($n = 20$) or “orthopedic symptoms” ($n = 12$). Less commonly reported indications for malunion correction were supraclavicular nerve entrapment ($n = 2$), costo-clavicular syndrome ($n = 1$), Paget-von-Schroetter syndrome ($n = 1$), subclavian and axillary vein compression ($n = 1$), and supraspinatus impingement ($n = 1$). For details, see Tables 1, 2, and 3. The reported time between injury and malunion correction surgery ranged from 4 weeks to 22 years (Table 1).

Surgical Technique

According to the data found in the articles, the majority of patients ($n = 77$) were treated with an osteotomy and ORIF, followed by either debridement, excision, or removal of excess callus or bone ($n = 19$). Resection of the clavicle was reported in 4 cases, with 2 partial and 2 total resections. In 1 case, a partial clavicle excision was combined with ORIF [5] and for 2 patients, a nerve exploration and decompression was performed (Table 2).

With regard to the underlying pathology, it was noted that 17 out of 19 patients presenting with thoracic outlet syndrome were treated with an osteotomy. As for brachial plexus lesions, 5 of the 8 reported patients had an osteotomy for correction of their clavicle malunion (Table 3).

Several different approaches to the clavicle were utilized: supraclavicular incision ($n = 31$), sagittal incision (in Langer’s lines) ($n = 29$), horizontal ($n = 7$), and transverse incision ($n = 1$). In 35 patients, this was not specified (Table 2).

Bone Graft

Bone graft was used in 32 patients to augment fixation after corrective osteotomy: local autograft in 2 cases, morcelized callus in 9 patients, and tricortical iliac crest autograft in 14 cases. In 7 cases, the bone graft was not further specified. In 51 cases, no bone graft was used, and in 20 cases this was not mentioned (N/A) (Table 2).

Fig. 1. Flow sheet for systematic review of the literature

Method of Fixation

The method of fixation varied according to the surgical treatment. In the majority of the cases, a plate was used for fixation ($n = 53$). In 6 patients, pins were used for fixation. Three studies [11, 15, 24] did not report any fixation for their patients ($n = 10$) and 9 authors ($n = 34$) did not specify (Table 2).

Outcome

The average follow-up time was 22.1 months ranging from 6 weeks to 9 years with an average time to union after surgery (reported in 6 studies [1, 3, 4, 19, 25, 35]) of 4 months ranging from 5 weeks to 9 months (Table 4).

Five studies [2, 24, 30, 33, 35] reported the Constant-Murley score ($n = 25$ patients), and 2 of these [2, 33] also used the UCLA score ($n = 10$). The Disabilities of the Arm, Shoulder, and Hand (DASH) score was used in 3 studies [13, 19, 35] ($n = 30$ patients). Nowak et al. [23] compared pre-operative and post-operative Constant-Murley scores and showed an average increase of 16 points after callus and scar tissue removal. Smekal and colleagues [35] presented similar results with an increase of 22 points from pre- to post-operatively after performing an osteotomy within the callus and fixation with an elastic stable intramedullary nail (ESIN). Applying the DASH score, McKee and associates [19] and Hillen et al. [13] showed improved values post-operatively compared with the pre-operative values following corrective osteotomy and plate fixation. Smekal and coworkers [35] demonstrated a similar improvement in

DASH scores after osteotomy with fixation using ESIN. One study [22] applied the Short-Form 36 quality of life questionnaire (1 patient) saying that the “patient returned to full-time work at regular job.” No outcome measure but a subjective improvement of symptoms was reported in 13 studies [1, 3–10, 15, 16, 25, 31] ($n = 30$ patients). Fujita and colleagues [11] applied a fingertip-pulse wave in order to measure the outcome after partial resection of the clavicle to treat thoracic outlet syndrome. Three studies [17, 29, 34] did not report on outcomes ($n = 22$) (Tables 4 and 5).

Only 4 studies reported any complications: Nowak et al. [23] had 1 refracture after callus removal resulting in a nonunion and Skutek and coworkers [33] had 1 loosening of the plate fixation after lengthening osteotomy 4 months after the index surgery, but reported a good outcome after revision to a dynamic compression plate. McKee et al. [19] reported loss of plate fixation in 1 case after corrective osteotomy and Hillen et al. [13] had 1 infection and 1 nonunion after sliding osteotomy and fixation with a pelvic reconstruction plate. Seven studies [1, 6, 9, 15, 22, 25, 35] did not encounter any complications, and in the remaining 14 studies, complications were not reported.

Discussion

Malunion of clavicle fractures, being a 3 dimensional deformity with typically shortening, anterior rotation, and medial-inferior displacement, can affect shoulder biomechanics [26] and result in persistent pain and impairment of shoulder function [18]. In this setting, the goal of surgical

Table 1 Patients (with regard to malunion criteria)

Study	Study design	Patients	Age (years)	Initial treatment	Malunion location	Malunion criteria	Clavicular shortening in cm	Time to surgery
Enker [10]	Case report	1	46	Non-op	N/A	Callus (hypertrophic)	N/A	N/A
Daskalakis [9]	Case report	1	N/A	N/A	N/A	Callus formation	N/A	N/A
Dannöhl [8]	Case report	1	36	N/A	N/A	Callus (hypertrophic)	N/A	6 m
Jahn [15]	Case report	1	41	Non-op	Lateral	Callus formation	N/A	11 m
Chen CE [4]	Case report	1	35	Non-op	Midshaft	Callus formation, downward displacement of distal fragment	N/A	8 m
Chen DJ [5]	Case series	2	38, 55	Non-op	N/A	Callus (hypertrophic), displacement	N/A	To diagnosis 6 m
Nowak [24]	Case series	8	29 (23–60)	Non-op	N/A	Callus formation (excessive), cranio-caudal and ventro-dorsal displacement	N/A	66 m (22–117)
Jupiter [16]	Case report	2	26, 27	Non-op	Midshaft	Callus (hypertrophic), deformity	N/A	7 w, 3 y
Naert [22]	Case report	1	20	Non-op	Lateral	Deformity (posteroinferior projection of medial fragment into the supraspinous fossa)	N/A	1 y 3 m
Smekal [35]	Case series	5	34 (23–44)	Non-op	Midshaft	Malrotation of distal fragment (caudally), with superior surface facing anterior	N/A	18 m (13–24)
Smekal [36]	Surgical technique	Same patients as Smekal [35]						
Bosch [2]	Case series	4	30 (20–55)	Non-op	Midshaft	Shortening	1.6 (0.9 to 2.2)	1.5 y (1–3)
Peters [28]	Case series	Same patients as Bosch [2]						
Chan [3]	Case series	4	31–38	Non-op	Midshaft 3x, lateral 1x	Shortening, symptomatic deformity, dorsal angulation	2 to 3	23 m (11–72)
Fujita [11]	Case report	1	32	Non-op	Midshaft	Shortening	N/A	N/A
Onstenk [25]	Case report	1	27	Non-op	Midshaft	Shortening, malrotation	N/A	8 m
Connolly [6]	Case report	1	36	N/A	N/A	Shortening	N/A	N/A
Skutek [33]	Surgical technique	6	29 ± 12 (17–55)	N/A	N/A	Shortening	1.5 ± 0.5 (0.9 to 2.2)	11 m (1–28)
McKee [19]	Case series	15	37 (18–57)	Non-op	Midshaft	Shortening, inferior and medial displacement of the distal fragment	2.9 (1.6 to 4)	3 y (1–15)
McKee [21]	Surgical technique	Same patients as McKee [19]						
Payandeh [27]	Surgical technique	Same patients as McKee [19]						
Hillen [13]	Case series	10	40 (21–57)	N/A	Midshaft	Shortening and rotation	2.4 (1.5 to 3.5)	25 m (5–261)
Smekal [34]	Case report	2	N/A	Non-op	Midshaft	Shortening or angulation, symptomatic loss of anatomic alignment	N/A	> 6 m
Santa Della [31]	Case series	4	29, 27, 60, 35	Non-op	Midshaft	N/A	N/A	N/A
Basamanian [1]	Abstract	9	N/A	N/A	N/A	N/A	N/A	6 m to 6 y
Potter [29]	Case series	5	N/A	Non-op	Midshaft	N/A	N/A	N/A
Rosenberg [30]	Case report	2	43, 30	N/A	Midshaft	N/A	N/A	Minimum 4 m
Coughlin [7]	Case report	1	39	N/A	N/A	N/A	N/A	N/A
Leroux [17]	Cohort study	15	N/A	ORIF	Midshaft	N/A	N/A	Median 14 (IQR 7.8 to 15.7 m)

N/A not mentioned, *m* months, *y* years, *w* weeks, *IQR* interquartile range

Table 2 Surgical treatment of clavicle malunion (with respect to method)

Study	Patients	Symptoms/secondary pathology	Method	Bone graft	Approach	Method of fixation—ORIF
Daskalakis [9]	1	Subclavian + axillary vein compression	Callus excision, ORIF, subclavian-axillary vein de-compression	N/A	N/A	N/A
Jahn [15]	1	Brachial plexus lesion	Callus removal	No	N/A	None
Basamania [1]	9	N/A	Callus debridement	Morsellized callus	In Langer's line over the clavicle	N/A
Nowak [24]	8	N/A	Callus removal, scar tissue removal	No	Incision over the callus, in the Langer's line	None
Jupiter [16]	2	Supraclavicular nerve entrapment	Exploration of supraclavicular nerves, nerve decompression	No	Horizontal incision over clavicle	Compression plate; 1x N/A
Dannöhl [8]	1	Costo-clavicular syndrome	Osteotomy (extension)	N/A	N/A	AO-reconstruction plate
Bosch [2]	4	N/A	Osteotomy	Tricortical iliac crest autograft	Sagittal approach	AO 3.5 compression plate (Synthes)
Peters [28]	Same patients as Bosch [2]			Autogenous iliac crest bone graft	N/A	3.5 DC Plate
Naert [22]	1	Supraspinatus impingement	Osteotomy, resection of posterior bony prominence	No	Sagittal incision	N/A
Chan [3]	4	N/A	Osteotomy, in 1 case additional anterior capsulorthraphy	Iliac crest autograft	Horizontal incision: 3x, vertical 1x	3.5-mm compression plate
Chen CE [4]	1	Delayed brachial plexus neuroparaxia	Osteotomy, resection of malunited bone, decompression of brachial plexus	No	N/A	Knowles pins
Onstenk [25]	1	Brachial plexus compression	Osteotomy	No	N/A	Pelvic reconstruction plate
Connolly [6]	1	Thoracic outlet syndrome	Osteotomy (double), remodeling of piece, and reinsertion	No	Transverse incision over the malunion site	Reconstruction plate
Skutek [33]	6	N/A	Osteotomy (lengthening) and debridement	Iliac crest autograft	Sagittal approach along Langer's lines	3.5-mm LC-DC plate and screws
McKee [19]	15	11/15: thoracic outlet syndrome	Osteotomy	No	Oblique incision along superior margin of clavicle	3.5-mm limited-contact dynamic compression plate
McKee [21]	Same patients as McKee [19]			Morselized callus	N/A	N/A
Payandeh [27]	Same patients as McKee [19]			N/A	Incision centered over deformity	Lag screw, precontoured low-profile plate or contoured small-fragment compression plate
Rosenberg [30]	2	N/A	Osteotomy	Autogenous bone graft	Horizontal incision	7-hole reconstruction plate; 7-hole DCP
Potter [29]	5	N/A	"Reconstruction" (probably osteotomy)	Yes	N/A	Compression plate
Hillen [13]	10	N/A	Osteotomy (sliding)	No	Oblique incision along superior margin of clavicle	Pelvic reconstruction plate
Smekal [34]	2	N/A	Osteotomy (corrective)	N/A	N/A	N/A
Smekal [35]	5	N/A	Osteotomy within callus, separating the 2 main original fracture fragments	No	Oblique incision above the clavicle	Elastic stable intramedullary nail
Smekal [36]	Same patients as Smekal [35]			N/A	Inline with Langer's line	Elastic stable intramedullary nail

Table 2 (continued)

Leroux [17] Santa Della [31]	15 4	N/A Brachial plexus lesion	Osteotomy Bone abrasion + neurolysis, osteotomy + graft + spur resection, osteotomy + graft, osteotomy + neurolysis Removal of clavicle (entirely) Resection (partial) of inferi- orly protruded part of the clavicle Partial resection of clavicle + ORIF, osteotomy+ ORIF + resection of pseudoaneurysm Claviculectomy; thrombectomy, subclavian vein repair	N/A Yes (2x) N/A No No No	N/A N/A N/A N/A N/A	N/A N/A N/A None Dynamic compression plate N/A
Enker [10]	1	Brachial plexus compression				
Fujita [11]	1	Thoracic outlet syndrome				
Chen DJ [5]	2	Thoracic outlet syndrome				
Coughlin [7]	1	Paget-Schroetter syndrome			Supraclavicular incision parallel to clavicle	

N/A not mentioned

intervention is the restoration of clavicle anatomy while creating an environment that is conducive to bony union [18].

As different operative treatment options have not yet been systematically compared, it was the intent of this article to review not only indications for operative treatment and its timing, but especially the possible surgical techniques (for different clinical situations) including the role of bone graft and methods of fixation, and also to present the reported results of these specific techniques.

Limitations

There are several limitations of this review article, primarily related to the inherent limitations of the studies on which this review was based. Most of the 29 studies were retrospective case reports/series with the majority published as level IV evidence. Prospective studies with clearly documented outcome parameters do not exist with regard to the surgical correction of clavicle malunions. Therefore, we were left with careful analysis and interpretation of available evidence and trying to compare the outcome after the various surgical treatment options for clavicle malunions. Additionally, the studies reviewed involved different methods of outcomes evaluation, and most did not present raw data for each patient included in the analysis. Also, the methodologies of the papers reviewed did not provide controls for bias, confounding, or chance, as the articles were mainly descriptive in nature. As such, our study is simply an observational review of mostly case series but it does, nevertheless, provide an excellent overview of the currently available literature.

Indications and Timing of Surgery

Reported indications for surgery were basically symptomatic malunions with functional limitation, pain, and neurological problems (thoracic outlet syndrome, brachial plexus compression, etc.). Moreover, cosmetic dissatisfaction due to increased callus formation and shortening seemed to lead toward surgery.

The reported time between trauma and malunion correction surgery varied enormously and ranged from 4 weeks to 22 years. Based on the studies reviewed here, the current evidence does not allow an impact of time to surgery on the outcome after correction of the clavicle malunion. It might nevertheless be important to consider an early correction of a clavicle malunion as it has been shown that, for acute displaced midshaft clavicle fractures, the early operative intervention has the advantage of easier restoration of clavicular anatomy requiring less soft tissue and bony dissection compared with delayed reconstruction of a clavicle malunion [29].

Surgical Techniques

The majority of patients ($n = 77$) in the 29 studies were treated with an osteotomy and subsequent ORIF. The next most frequent management choice was

Table 3 Surgical treatment according to underlying pathology

Study	Patients	Symptoms/secondary pathology	Method
Enker [10]	1	Brachial plexus compression	Removal of clavicle (entirely)
Jahn [15]	1	Brachial plexus lesion	Callus removal
Onstenk [25]	1	Brachial plexus compression	Osteotomy, ORIF
Santa Della [31]	4	Brachial plexus lesion	Bone abrasion + neurolysis, osteotomy + graft + spur resection, osteotomy + graft, osteotomy + neurolysis
Chen CE [4]	1	Delayed brachial plexus neurapraxia	Osteotomy, resection of malunited bone, decompression of brachial plexus
Daskalakis [9]	1	Subclavian + axillary vein compression	Callus excision, ORIF, subclavian-axillary vein decompression
Dannöhl [8]	1	Costo-clavicular syndrome	Osteotomy (extension)
Naert [22]	1	Supraspinatus impingement	Osteotomy, resection of posterior bony prominence
Jupiter [16]	2	Supraclavicular nerve entrapment	ORIF, exploration of supraclavicular nerve, nerve decompression
Coughlin [7]	1	Paget-Schroetter syndrome	Claviculectomy; thrombectomy, subclavian vein repair
Fujita [11]	1	Thoracic outlet syndrome	Resection (partial) of inferiorly protruded part of the clavicle
Connolly [6]	1	Thoracic outlet syndrome	Osteotomy (double), remodeling of piece and reinsertion
Chen DJ [5]	2	Thoracic outlet syndrome	Partial resection of clavicle + ORIF, osteotomy + ORIF + resection of pseudoaneurysm
McKee [19]	15	Thoracic outlet syndrome	Osteotomy

debridement, excision, or removal of excess callus or bone ($n = 19$), but also other techniques like resection of the clavicle or nerve exploration and decompression were reported.

Unfortunately, the selected articles describing an osteotomy often lack information about additional debridement, excision, or removal of callus. Therefore, we reported them as 2 different categories.

Bone Graft

The indication for use of bonegraft/autograft in malunion corrections cannot be determined by this study as the included articles lack detailed information. The authors rarely used bone graft (51 cases) or did not report it (20 cases). They might have simply used local bone graft. After having recreated the original fracture during a correction osteotomy, there usually is abundant local bone (former callus) which can be used for restoration of length. There are no studies comparing malunion corrections with or without the use of bone graft. Even though bone grafting does not seem to be necessary in all cases, it is an accepted technique for the treatment of clavicle malunions, not only to regain the necessary clavicle length but also to facilitate bone healing.

Method of Fixation

In the literature, both compression plating and intramedullary fixation have been described for the fixation after correction of clavicle malunion [18]. In the studies of this systematic review, the preferred method of fixation after corrective osteotomy was plate fixation (in 53 cases) followed by pin fixation in 6 patients. McKee et al. [19] used a 3.5 dynamic compression plate for fixation, Hillen et al. [13] a pelvic reconstruction plate, and Smekal et al. [35] an elastic

stable intramedullary nail (ESIN) once the correction had been achieved.

Outcome

Though all of the included studies involved small series, all of them reported a favorable outcome after correction of the clavicle malunion. Comparison of outcomes was difficult due to the heterogeneity of methods used for outcome assessment. Bosch et al. [2] and Skutek et al. [33] presented similar UCLA scores after performing a corrective osteotomy. With regard to the Constant and Murley score, both studies showed comparable improvements, similar to the data reported by Nowak and colleagues [23] doing a callus resection. McKee and associates [19], Hillen et al. [13], and Smekal et al. [35] (performing osteotomies) presented all similarly improved DASH scores with values twice as good post-operatively compared with pre-operatively.

In general, the treatment of symptomatic clavicle malunion requires an osteotomy in order to restore anatomic alignment including clavicle length and rotation prior to internal fixation [18]. A correction of the excessive callus will not improve the biomechanics of the shoulder joint, though it might be a good surgical treatment option in case of neurovascular impairment due to compression. One of our senior authors (MDM) has experienced “unhappy” patients after merely removing excessive callus in case of symptomatic clavicle malunions. In his experience, corrective osteotomy with plate fixation results in a better resolution of symptoms and better patient satisfaction.

Based on the available data, no fixation method seemed to be superior when reviewing the study outcomes; however, it must be noted that high-quality evidence, for instance comparing 2 fixation methods after clavicle malunion correction in a randomized blinded study, were not identified in the present review. With regard to displaced midshaft clavicle fractures, there are

Table 4 Outcome (with regard to the surgical method)

Study	Patients	Method	Follow-up	Time to union	Type of scoring	Pre-op	Post-op
Daskalakis [9]	1	Callus excision, ORIF, subclavian-axillary vein decompression	N/A	N/A	Surgeon's evaluation		Symptoms subsided, phlebography confirmed free blood flow
Jahn [15]	1	Callus removal	N/A	N/A	Surgeon's evaluation		Weakness in forward elevation and tingling resolved
Basamania [11]	9	Callus debridement	N/A	< 8 w	Surgeon's evaluation		Clavicular length restored to within 5 mm of normal, all patients satisfied
Nowak [24]	8	Callus removal, scar tissue removal	20 m (12–48)	N/A 1x nonunion	Constant-Murley	77 (58–84)	93 (87–100)
Rosenberg [30]	2	ORIF	N/A	N/A	Constant-Murley	N/A	24; 82
Jupiter [16]	2	ORIF, exploration of supraclavicular nerves, nerve decompression	12 m; 14 m	N/A	surgeon's evaluation		Resolution of symptoms (dysaesthesia, disabling pain)
Potter [29]	5	ORIF	N/A	N/A	N/A		N/A
Bosch [2]	4	Osteotomy	6 w to 4 y	N/A	Constant-Murley; UCLA score	N/A	89 (63–100); 27 (18–30)
Peters [28]	Same patients as Bosch [2]						
Skutek [33]	6	Osteotomy (lengthening) and debridement	3.9 ± 3.2 y (range 0.4 to 9 y)	N/A	Constant-Murley; UCLA score	N/A	95 ± 8.4; 32.5 ± 3.8
Smekal [35]	5	Osteotomy within callus, separating the 2 main original fracture fragments	6 m	4.4 m (3–6)	DASH; Constant score	36.5 (12–69); 72.4 (52–88)	2.3 (0–6) / 94.4 (91–100)
Smekal [36]	Same patients as Smekal [35]						
McKee [19]	15	Osteotomy	20 m (12–44)	14/15; 8 w (5–17); 1x nonunion	DASH	32	12
McKee [21]	Same patients as McKee [19]						
Payandeh [27]	Same patients as McKee [19]						
Hillen [13]	10	Osteotomy (sliding)	37 m (14–56)	N/A 1x nonunion	DASH	78 (53–100)	45 (2–74)
Naert [22]	1	Osteotomy, resection of posterior bony prominence	3 m	N/A	Short-Form 36 quality of life		Return to full-time work at regular job
Dannöhl [8]	1	Osteotomy (extension)	N/A	N/A	Surgeon's evaluation		Resolution of neurologic symptoms (plexus compression) 3x, cosmetics better 1x
Chan [3]	4	Osteotomy, in 1 case additional anterior capsulorrhaphy	24 m (16–39)	6 w	Surgeon's evaluation		No symptoms
Chen CE [4]	1	Osteotomy, resection of malunited bone, decompression of brachial plexus	1 y	3 m	Surgeon's evaluation		Good sensibility
Onstenk [25]	1	Osteotomy, ORIF	9 m	9 m	Surgeon's evaluation		Normalization of pre-operative brachial plexus symptoms
Connolly [6]	1	Osteotomy (double), remodeling of piece and reinsertion	12 m	N/A	Surgeon's evaluation		Symptom relief (thoracic outlet syndrome, disabling pain)
Smekal [34]	2	Osteotomy (corrective)	N/A	N/A	N/A		N/A
Leroux [17]	15	Osteotomy	N/A	N/A	N/A		N/A
Santa Della [31]	4	Bone abrasion + neurolysis, osteotomy + graft + spur resection, osteotomy + graft, osteotomy + neurolysis	N/A	N/A	Surgeon's evaluation		3x improved symptoms, 1x: unchanged
Enker [10]	1	Removal of clavicle (entirely)	N/A	N/A	Surgeon's evaluation		Pain and paresthesias resumed
Chen DJ [5]	2		3 m	N/A	Surgeon's evaluation		Fully recovered, excellent function, good anatomic reduction of clavicle

Table 4 (continued)

		Partial resection of clavicle + ORIF, osteotomy+ ORIF + resection of pseudoaneurysm	12 m	N/A	Surgeon's evaluation Fingertip-pulse wave	Return to normal activities, excellent cosmetic result Normal fingertip-pulse wave
Coughlin [7]	1	Claviculectomy; thrombectomy, subclavian vein repair				
Fujita [11]	1	Resection (partial) of inferiorly protruded part of the clavicle	N/A	N/A		

N/A not mentioned, w weeks, m months, y years

studies showing similar functional outcomes for both methods of fixation [12, 37]. Though hardware migration has been a common problem, intramedullary fixation seems to have the shorter operative time [37]. Furthermore, the preservation of the soft tissue envelope and periosteum can accelerate fracture healing [12]. Nevertheless, plate fixation seems to be the standard surgical fixation [12]. One reason might be that, compared to intramedullary devices, it provides more stability regarding rotation and distraction. Even if clavicular plates require larger skin incisions and more soft tissue stripping, they seem to have a more rapid functional improvement the first 6 months after surgery [37].

Time to union varied widely and was reported only in a few studies. Also, it was not reported how often radiographs for union were performed. Thus, the data generated in this review did not allow comparison of different surgical techniques or method of fixation with regard to time to union.

Surgical management of symptomatic malunion can be associated with a number of potential complications and therefore must be considered [18]. Apart from hardware irritation requiring plate removal, infection, failure of fixation, and nonunion can be possible complications [14]. In general, patients with former malunion of the clavicle show a good healing potential after correction of the deformity. In this review, only 4 studies [13, 19, 24, 33] reported complications. In 3 cases, this was after an osteotomy: Skutek and colleagues [33] had 1 loosening of the reconstruction plate for fixation after lengthening osteotomy 4 months after the index surgery. McKee and coworkers [19] had 1 loss of plate fixation after correction osteotomy as well as 1 nonunion, and Hillen et al. [13] had 1 infection and 1 nonunion after sliding osteotomy using a pelvic reconstruction plate for fixation. In Nowak et al.'s [23] study, there was 1 refracture after callus removal resulting in a nonunion.

The overall complication rate in the 103 patients of this review was low with less than 6%. Complications were predominantly found after corrective osteotomy, which may have been due to the fact that this was the predominant surgical strategy ($n = 70$).

In conclusion, the reported surgical techniques of clavicular malunion correction seem to be acceptable with a good clinical outcome. In the majority of the cases, the authors performed a corrective osteotomy followed by plate fixation. This seems to be the preferred technique in the literature, as the primary goal of surgical intervention should be the restoration of clavicle anatomy (especially length, rotation, and alignment) while creating an environment that is conducive to bony union [18]. A rigid fixation by means of a plate to prevent rotation and allow early mobilization seems to be the best option for most patients with clavicle malunions.

Even though further studies will be needed to compare the surgical techniques and their specific outcome in a prospective manner, this review article can be used as a reference to guide operative treatment decisions for patients presenting with a clavicle malunion.

Table 5 Outcome—shoulder scores

Study	Patients	Method	Type of scoring	Pre-op	Post-op
Nowak [24]	8	Callus removal, scar tissue removal	Constant-Murley	77 (58–84)	93 (87–100)
Rosenberg [30]	2	ORIF	Constant-Murley	N/A	24; 82
Bosch [2]	4	Osteotomy	Constant-Murley; UCLA score	N/A	89 (63–100); 27 /18–30)
Skutek [33]	6	Osteotomy (lengthening) and debridement	Constant-Murley; UCLA score	N/A	95 ± 8.4; 32.5 ± 3.8
McKee [19]	15	Osteotomy	DASH	32	12
Hillen [13]	10	Osteotomy (sliding)	DASH	78 (53–100)	45 (2–74)
Smekal [35]	5	Osteotomy within callus, separating the 2 main original fracture fragments	DASH; Constant score	36.5 (12–69); 72.4 (52–88)	2.3 (0–6) / 94.4 (91–100)

DASH disability of the arm and shoulder and hand, *UCLA score* The University of California at Los Angeles score, *N/A* not mentioned

Compliance with Ethical Standards

Conflict of Interest: Claudia C. Sidler-Maier, MD, and Nicolas J. Dedy, MD, PhD, have declared that they have no conflict of interest. Michael D. McKee, MD, FRCS (C), reports personal fees as a designer from Stryker and as a consultant from Zimmer, Acumed, and ITS, outside the work. In addition, Dr. McKee receives royalties from Stryker for a patent. Emil H. Schemitsch, MD, FRCS (C), reports grants and personal fees from Stryker, Smith & Nephew, and Zimmer; personal fees from Amgen, Bioventus, Acumed, Sanofi, and Pendopharm; and non-financial support from ITS, outside the work.

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