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How to treat a Midclavicular Nonunion: A Narrative Review

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Background

For many years, there was a (mis)belief among trauma surgeons that the nonunion rate of nonoperatively treated clavicular fractures was extremely rare, with a frequency of 1-3% (1). Treatment and patient counseling were based on the motto: “A clavicle fracture heals with, without or instead of medical treatment.” However, many studies have shown that the nonunion rate of the clavicle in adults undergoing nonoperative treatment is significantly higher, around 5-15%, than previously assumed (2). The treatment of clavicular nonunion is technically demanding and a socioeconomically burdensome factor.

Aim of the Review

The aim of this review article is to summarize the current causes associated with an increased risk of nonunion of midshaft clavicle fractures and to provide a clear overview of the currently available treatment options.

Definition

The conditions under which a non-healing clavicular fracture is termed nonunion are not consistently defined in the literature. Traditionally, periods ranging from 16 weeks to 6 months have been defined. Robinson (3) defined radiological evidence of bridging callus in X-rays, as well as pain relief and stability at the fracture gap under load, as definite signs of bone consolidation in his epidemiological study. If these defined clinical and radiological signs were not present after a period of 24 weeks, it was considered a sign of nonunion (3).

Recently, a much more pragmatic definition has been established, which considers nonunion to be present when the treating trauma surgeon determines that the fracture has no potential for healing without further intervention (4). This definition accounts for the individual and sometimes therapy-dependent time span in which bone healing can be expected.

Under nonoperative treatment of a clavicular fracture, a lack of healing can be reliably predicted both clinically and radiologically after just a few weeks, while after stable osteosynthesis without radiological signs of implant loosening, bony consolidation can take 12 to 18 months (5, 6).

Epidemiology

Nonunion after Nonoperative Treatment

Rowe (1) reported in 1968 a nonunion rate of less than 1% under conservative treatment. The majority of patients in this case series were children, in whom clavicular nonunion is an absolute rarity (7). Hill (8) found nonunion after midclavicular fracture in 15% of his patients and described a significant correlation with an initial shortening of more than 2 cm. In a detailed prospective study from January 1997 to March 2001 on 868 adult patients, a cumulative nonunion rate of 62% was found after a period of 24 months (3). In two more

recent systematic reviews (9, 10), nonunion rates of 15-24% were found for the central clavicle after conservative treatment.

Nonunion after Surgical Treatment

Nonunion after surgical treatment occurs significantly less frequently than under nonoperative therapy. In a recent meta-analysis, 497 surgically treated and 457 conservatively treated fractures from 11 prospective randomized studies were included. The operated cases showed a nonunion rate of 1.4%, while a nonunion rate of 14% was found in the non-operatively treated group (9). The nonunion rate under conservative therapy is 10 times higher than after surgical treatment.

Risk Factors (Tab. 1)

Table 1: Risk Factors for Clavicle Nonunion
Fracture Morphology
Displacement
Age
Sex
High-Energy-Trauma
Refracture
Smoking

Risk Factor Displacement

Studies by various groups have shown that the degree of primary displacement affects the development of nonunion. In Jupiter's patient cohort (11), the degree of displacement was the only significant prognostic factor. Wick (12) showed that over 90% of patients with delayed healing or nonunion had an initial shortening of more than 2 cm.

Risk Factor Fracture Morphology

Several studies have shown that multifragmentary fractures of the clavicle are associated with a significantly higher risk of nonunion than simple fractures (2, 3, 5, 13).

Risk Factor Sex

Women have a relatively higher risk of developing nonunion after a clavicular fracture than men (2, 3, 13, 14). In absolute numbers, nonunion is more frequently observed in men, as they also suffer fractures more often.

The “Brinker’s Table” (Tab. 2)

Table 2: Nonunion Rate under nonoperative Treatment								
Age (years)	Fracture Morpholpgy							
	simple non-displaced		simple displaced		comminuted non-displaced		comminuted displaced	
	♀	♂	♀	♂	♀	♂	♀	♂
25	3 %	< 1 %	19 %	8 %	7 %	3 %	33 %	20 %
35	4 %	< 1 %	20 %	11 %	8 %	4 %	35 %	21 %
45	5 %	1 %	25 %	14 %	10 %	5 %	37 %	25 %
55	6 %	2 %	28 %	18 %	12 %	6 %	42 %	29 %
65	7 %	3 %	33 %	20 %	18 %	7 %	47 %	33 %

In a prospective study by Robinson (3), fractures were further differentiated to identify risk factors for the development of nonunion. These data were further analyzed by the Brinker group (15), resulting in the so-called “Brinker Table,” where the risk of nonunion under conservative treatment is differentiated by fracture displacement, fracture form (simple/multifragmentary), age, and gender of the patients. A clavicular fracture is considered displaced when the two main fragments no longer have cortical contact in both X-ray planes or the axis has an angulation of more than 30° (15). The results are presented in Table 2.

Risk Factor Impact of Trauma

Many studies have found that nonunion rate is higher in high-energy accidents than in simple falls (16) . This observation can be explained by the fact that high-energy accidents more

frequently cause displaced and multifragmentary fractures, which then have an increased risk of nonunion.

Risk Factor Refracture

In some patient cohorts, refracture after a previously healed clavicular fracture was identified as a risk factor. Wilkins (17) found seven patients with clavicular nonunion among 31 patients who had previously sustained a clavicular fracture between 3 months and 11 years before the current fracture. Clavicle refractures are mainly observed after plate removal (18, 19). The frequency is reported in the literature as 5-6% (18, 19).

Other Risk Factors

Other general risk factors for the development of nonunion include nicotine abuse and obesity, typical age-related comorbidities such as diabetes mellitus, or the use of NSAIDs (5, 14, 20, 21). Premature mechanical loading, a lateral clavicle fragment larger than 3 centimeters, and a delay before surgery can also increase the risk of fracture healing failure (21).

Diagnostics

The diagnosis of clavicular nonunion is based on the patient's history, clinical examination, and imaging diagnostics.

Leading Symptom Pain

The leading symptom is pain, which is reported by approximately 75% of patients with clavicular nonunion (4). Typically, patients complain of pain when moving the arm in the shoulder joint, radiating into the arm, hand, or/and neck. Some patients describe audible and palpable “crackling” and “rubbing phenomena” or persistent instability over the fracture (4).

Clinical Findings

Malposition and Instability

In clinical examination, typical malposition can often be observed in atrophic nonunion of the clavicular shaft: the contours of the shoulder girdle appear asymmetrical. The affected shoulder is lower and rotated medially. The medial main fragment is prominently palpable under the skin. Palpably, the instability of the main fragments during shoulder movements is noticeable.

In hypertrophic nonunion, the malposition appears generally more discreet. Here, pain is the main symptom, and instability and malposition are less pronounced. At the level of the nonunion, there is a visible and often tender callus bulge under the skin.

Neurological Deficits and Vascular Damage

Neurological symptoms are found in about 6%-52% of patients with clavicular nonunion (22-24). Excessive connective tissue callus masses at the lower edge of the clavicle seem responsible for this, narrowing the space under the clavicle and the first rib, possibly provoking a “thoracic outlet syndrome.” Secondary vascular problems, primarily in the form of thrombosis of the subclavian vein, can also be caused by hypertrophic connective tissue masses (25).

Restricted Mobility

In some patients with clavicular nonunion, painful restriction of movement in the affected shoulder girdle can be detected. Usually, abduction and anteversion, as well as external rotation of the arm, are affected (26).

X-ray Findings

To confirm the diagnosis, an initial X-ray of the clavicle in standard planes is performed. In the classic case of atrophic nonunion, the displaced main fragments show no callus formation. Hypertrophic nonunion is characterized by an excessive callus bulge. In individual cases, it can be challenging to recognize nonunion as such in conventional X-rays. Especially in hypertrophic nonunion, the nonunion gap can be irregular, so it is overlaid by callus masses. In these cases, a CT scan of the clavicle should be ordered to confirm the diagnosis (16).

Classification of Clavicle Nonunion (Tab. 3)

Table 3: Classification			
	vital		avital
X-Ray	hypertrophic	oligotrophic	atrophic
Problem	mechanical		biological

Causes	instability at the fracture gap	decreased vascularization
	implant too weak	infection
	implant loosening	congenital

Descriptive Classification

In the clavicle, as in any other bone, nonunion is distinguished based on the radiomorphological appearance as hypotrophic, oligotrophic, and hypertrophic nonunion (16). Hypotrophic nonunion always indicates a biological problem. The bone is unable to form callus (16). The hypertrophic and oligotrophic nonunion within the first year after the accident is an expression of a purely mechanical problem: instability at the fracture gap. Within this period, it is usually entirely sufficient to solve the mechanical problem in the form of stable osteosynthesis. After this period, a combination form is present: continued instability with a lack of new bone formation.

Classification of Cause

Classifying the cause of a lack of bone healing in the clavicle is useful for taking appropriate therapeutic measures. The causes of nonunion can be mechanical problems, biological problems, or a combination of mechanical and biological problems (4).

The development of nonunion after nonoperative therapy is often attributed to a mechanical problem (instability at the fracture gap), while clavicle nonunion after osteosynthesis with an intact implant reflects a biological problem (circulatory disorder of the fragments) (4). Special forms of a biological problem include infectious nonunion (27, 28) and congenital nonunion (29).

Therapy

The general principle applies to the therapy of clavicular nonunion: Only symptomatic nonunion requires (surgical) treatment (6). Asymptomatic nonunion, for example, incidentally, discovered radiologically, does not require any further specific measures.

Nonoperative Treatment

The literature describes several non-surgical measures for treating clavicular nonunion. These include the local application of pulsed electromagnetic fields (magnetic field therapy), local ultrasound treatment, or focused shock wave therapy (16). Reports that fractures have healed under such treatment are rare. However, many patients initially choose one of these non-surgical measures in the hope of avoiding surgery, despite the low success rates (16).

Indications for Surgical Treatment and Timing

Indications for surgical therapy of clavicular nonunion exist in cases of pain, painful movement restrictions, severe malposition, or neurovascular problems that can be attributed to the nonunion (6, 16).

Making the indication requires a thorough clinical examination that allows differential diagnosis of the presented symptoms. Besides qualitatively assessing the symptomatology, attempts should be made to quantify the symptoms and assess the patient's suffering and expectations. In individual cases, a patient may objectively have only minor functional deficits but be very unhappy with the malposition or large callus bulge and have significant suffering. On the other hand, some patients objectively have a considerable functional deficit but can manage well in daily life and work. Under stable osteosynthesis and vital conditions, a healing rate of over 90% can be expected (30). However, regarding indication, it must also be considered that surgical treatment of clavicular nonunion is associated with a double risk of infection compared to osteosynthesis of a fresh clavicular fracture (31). Regarding the timing of surgery, it was found that a surgical intervention for a noticeably delayed healing under conservative primary therapy up to the third month after the accident has about the same risk profile as the osteosynthesis of a fresh fracture (32).

These data support an early indication for surgical therapy if, under nonoperatively initiated treatment, clinically persistent symptoms and radiologically absent callus formation, the development of nonunion is foreseeable.

Goal of the Operation

The aim of the operation is to create vital conditions, restore the length of the clavicle, and achieve a stable osteosynthesis. The basic principles of surgical treatment for clavicular nonunion are independent of the location and type of nonunion.

Vitality

To ensure vital conditions, the fibrous pannus of the nonunion and non-viable bone fragments must be removed, regardless of the size of the resulting bone defect. A sparing decortication of the main fragments follows. The principle applies: the older the nonunion and the more non-viable the fragments, the larger the bone defect that needs to be bridged.

Stability and Implant Choice

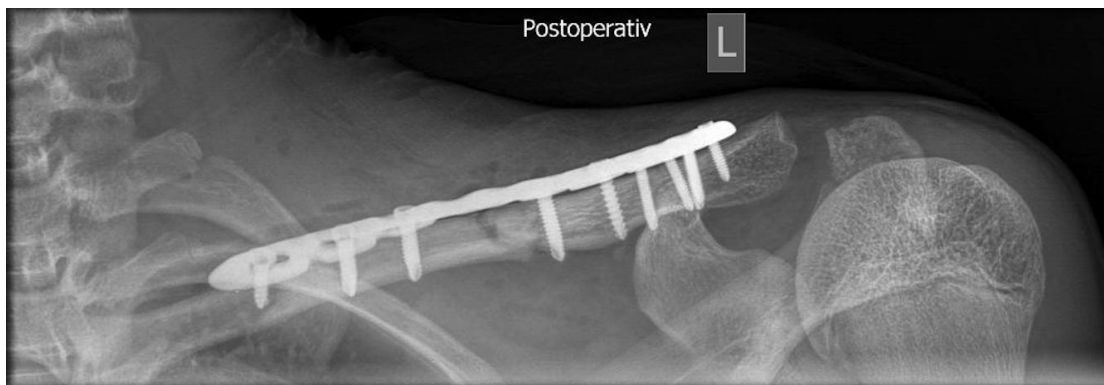
Various implants are described in the current literature that can be used to achieve adequate stability in the case of a primary intervention for clavicular nonunion. Besides various intramedullary implants (6) or external fixators (33), different plate designs are mainly used (10, 34). From a biomechanical point of view, plate osteosynthesis seems to have advantages over intramedullary procedures (35), so this procedure is preferred by many authors (10, 34). Anatomically preformed angle-stable implants offer more stability in the case of nonunion than non-angle-stable plates. Reconstruction plates that can be adapted to the clavicle's anatomy are generally too weak and prone to implant fatigue (34). Thus, anatomically preformed angle-stable plates offer significant advantages and sufficient stability (36). Under stable osteosynthesis and vital conditions, a healing rate of over 90% can be expected (37).

Plate Position

Regarding the question of plate position, there are no clear recommendations in the current literature. In principle, the classic superior plate position is recommended for primary interventions in clavicular nonunion (37). For revision interventions after previous surgical treatment, the antero-inferior plate position can have advantages, as significantly longer screw lengths can be used (38) (See example 2, Figures 3 and 4). However, the effort to place a plate in the antero-inferior position is considerably greater, as the ventral muscle attachments must be detached, and the plate must be significantly pre-bent laterally if no anatomically preformed implant is used.



Fig. 1: 16-year-old patient. Nonunion and implant failure 5 months after primary treatment of a central clavicle fracture with and titanium elastic nail.



Figs. 2 and 3: Surgical revision with implant removal, open reduction, decortication, and stable fixation with a preshaped 3.5/2.7 mm angle-stable plate.

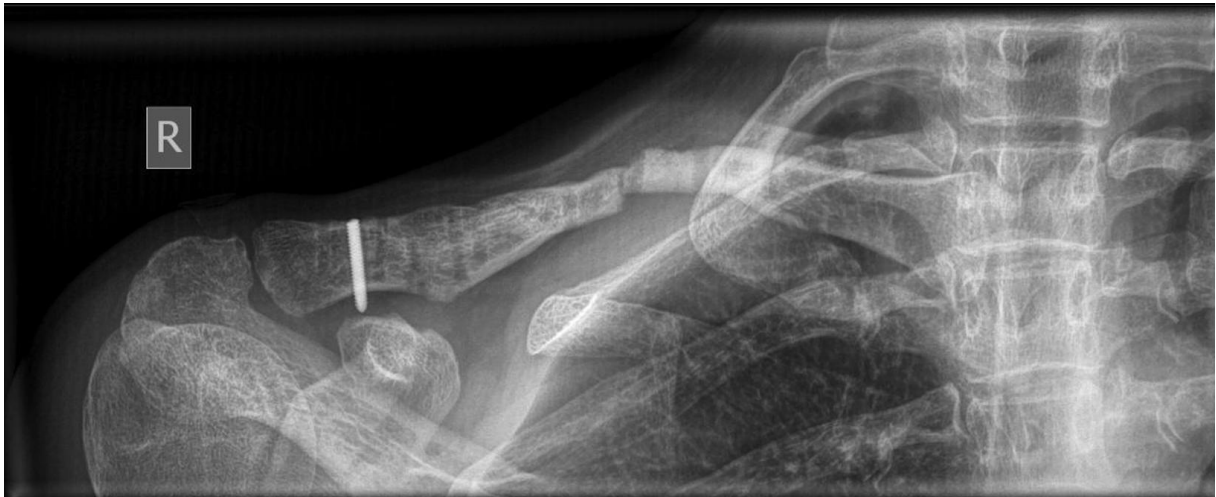


Fig. 4 Atrophic nonunion after removal of a fixed angle plate in a 56-year-old female patient, 10 months after the primary osteosynthesis.



Fig. 5

Surgical revision with nonunion resection, decortication, open reduction, and stable osteosynthesis with a 3.5 mm angle-stable plate pre-bent with a bending press. Note the significantly longer screws. Additionally, autologous cancellous bone and a resorbable ceramic bone substitute material were applied around the main fragments.

Double Plating

A double plate osteosynthesis of the clavicle is understood as placing both an antero-inferior and a superior plate (39) . This is a salvage maneuver that can be used in revision interventions after clavicular nonunion with already significantly reduced bone quality or in the case of long bone defects to ensure sufficient stability (39) (See example 3, Figures 5 and 6).

Bone Replacement and Defect Filling

Autologous Bone Graft from the Iliac Crest

Autologous bone grafts from the iliac crest are considered the gold standard in treating avital nonunion or bone defects that are used in addition to stable osteosynthesis to treat clavicular nonunion (16), (40). The autologous iliac bone has good osteoconductivity and excellent osteoinductive properties. Even larger defects of 3 to 6 cm in length on the clavicle could be successfully bridged with tricortical iliac crest grafts (41). The disadvantages associated with harvesting autologous bone grafts include frequent postoperative complaints and problems at the harvest site, longer operating times, an increased risk of bleeding, and the limited amount of bone material that can be obtained.

Allogeneic Bone Substitute Material

Allogeneic bone substitute materials, such as demineralized bone matrix or ceramics, can generally be used for smaller defects and gaps between the main fragments created after decortication (42). The osteoconductive properties of these materials are sufficient to ensure bridging of the nonunion after stable osteosynthesis.

Vascularized Grafts

For larger defects or revision interventions, using a vascularized microvascular graft should be considered (43). This includes the fibula graft, with which defects up to 10 cm in length can be bridged. An alternative is a vascularized graft from the medial femoral condyle or a vascularized rib graft. Typically, the vessels are connected to the thyrocervical artery and the external jugular vein.

Induced Membranes (Masquelet Technique)

The innovative Masquelet technique has proven effective in recent years for treating nonunion of long bones (16) and could also be successfully used on the clavicle (44) (45). It is a two-stage procedure that utilizes a foreign body reaction induced by a PMMA spacer, which is

shaped and inserted into the defect after initial debridement (16). After 4-8 weeks, the cement spacer is removed, leaving a chamber and a well-vascularized membrane that can accommodate the osteoconductive bone material (16).

Results of Surgical Treatment

What Can the Patient Expect?

Current literature shows that bone healing of clavicular nonunion after surgical treatment, considering the principles mentioned above, can be reliably achieved. Satisfactory functional results and a good healing rate can be achieved with the superior and antero-inferior plate position and double plate osteosynthesis. Nevertheless, it has been shown that shoulder function in some cases only recovers very slowly and not entirely (31). With adequate indication, a good functional result and reliable bone healing can also be achieved with an elastic titanium nail (6).

Conclusions

Successful treatment of symptomatic clavicular nonunion requires precise diagnostics and preoperative differentiation regarding tissue vitality. Unstable vital hypertrophic nonunion can be successfully treated with stable osteosynthesis and the addition of allogeneic bone substitute material. If there is a vitality problem in the form of hypotrophic nonunion, it is usually necessary to add autologous bone material alongside decortication and stable osteosynthesis. Bone defects can be bridged with iliac crest grafts or vascularized bone transplants. An alternative is the Masquelet technique. After previous surgeries, the possibility of infection should also be considered. The antero-inferior plate position offers a good alternative to the superior plate position after previous interventions. In some cases, a double plate osteosynthesis may be useful after multiple interventions to ensure sufficient stability.

References

- [1] Rowe CR. An atlas of anatomy and treatment of midclavicular fractures. *Clin Orthop*. 1968;58:29–42.
- [2] Brinker MR, and O'Connor DP. The incidence of fractures and dislocations referred for orthopaedic services in a capitulated population. *J Bone Joint Surg Am*. 2004;86-A(2):290–7.

- [3] Robinson CM, Court-Brown CM, McQueen MM, and Wakefield AE. Estimating the risk of nonunion following nonoperative treatment of a clavicular fracture. *J Bone Joint Surg Am.* 2004;86-A(7):1359–65.
- [4] Brinker MR, and O'Connor DP. In: Browner BD, Jupiter JB, Ch. K, and A. A eds. *Skeletal Trauma*. Philadelphia: Elsevier; 2019:743–834.
- [5] Jorgensen A, Troelsen A, and Ban I. Predictors associated with nonunion and symptomatic malunion following non-operative treatment of displaced midshaft clavicle fractures--a systematic review of the literature. *Int Orthop.* 2014;38(12):2543–9.
- [6] Jubel A, Andermahr J, Weisshaar G, Schiffer G, Prokop A, and Rehm KE. [Intramedullary nailing (ESIN) in clavicular pseudoarthroses. Results of a prospective clinical trial]. *Unfallchirurg.* 2005;108(7):544–50.
- [7] Yahya A, Mehlman CT, Kim J, Little KJ, and Parikh SN. Nonunion of the Clavicle Among Children: A Review of the Literature and a Report of Three New Cases. *Orthopedics.* 2022;45(4):e190–e5.
- [8] Hill JM, McGuire MH, and Crosby LA. Closed treatment of displaced middle-third fractures of the clavicle gives poor results [see comments]. *J Bone Joint Surg Br.* 1997;79(4):537–9.
- [9] Amer K, Smith B, Thomson JE, Congiusta D, Reilly MC, Sirkin MS, et al. Operative Versus Nonoperative Outcomes of Middle-Third Clavicle Fractures: A Systematic Review and Meta-Analysis. *J Orthop Trauma.* 2020;34(1):e6–e13.
- [10]Lenza M, Buchbinder R, Johnston RV, Ferrari BA, and Faloppa F. Surgical versus conservative interventions for treating fractures of the middle third of the clavicle. *Cochrane Database Syst Rev.* 2019;1(1):CD009363.
- [11]Jupiter JB, and Leffert RD. Non-union of the clavicle. Associated complications and surgical management. *J Bone Joint Surg Am.* 1987;69(5):753–60.
- [12]Wick M, Muller EJ, Kollig E, and Muhr G. Midshaft fractures of the clavicle with a shortening of more than 2 cm predispose to nonunion. *Arch Orthop Trauma Surg.* 2001;121(4):207–11.
- [13]Ban I, and Troelsen A. Risk profile of patients developing nonunion of the clavicle and outcome of treatment--analysis of fifty five nonunions in seven hundred and twenty nine consecutive fractures. *Int Orthop.* 2016;40(3):587–93.

- [14]Manokian E, van Olden GDJ, and Al Shaer S. Predictors of nonunion after nonoperative treatment of displaced midshaft clavicle fractures. *Injury*. 2025;56(10):112657.
- [15]Brinker MR, Edwards TB, and O'Connor DP. Estimating the risk of nonunion following nonoperative treatment of a clavicular fracture. *J Bone Joint Surg Am*. 2005;87(3):676–7; author reply 7.
- [16]Brewer J, O'Connor DP, and Brinker MR. In: Ricci WM, and Mehta S eds. *Orthopaedic knowledge update, OKU 6*. Philadelphia, Rosemont, Illinois: Wolters Kluwer; American Academy of Orthopaedic Surgeons; 2023:91–102.
- [17]Wilkins RMJ, R.M. Ununited fractures of the clavicle. *J Bone Joint Surg*. 1983;65A:774–8.
- [18]Tsai SW, Ma HH, Hsu FW, Chou TA, Chen KH, Chiang CC, et al. Risk factors for refracture after plate removal for midshaft clavicle fracture after bone union. *J Orthop Surg Res*. 2019;14(1):457.
- [19]Zhu Y, Hu J, Zhan T, Zhu K, and Zhang C. Refracture after plate removal of midshaft clavicle fractures after bone union-incidence, risk factors, management and outcomes. *BMC Musculoskelet Disord*. 2023;24(1):308.
- [20]Irfan SA, Ali AA, Ashkar A, Akram U, Fatima S, Baig MMA, et al. Predictors requiring special attention to prevent clavicle fracture nonunion: a systematic review of literature. *Trauma Surg Acute Care Open*. 2023;8(1):e001188.
- [21]Zura R, Mehta S, Della Rocca GJ, and Steen RG. Biological Risk Factors for Nonunion of Bone Fracture. *JBJS Rev*. 2016;4(1).
- [22]Kay SP, and Eckardt JJ. Brachial plexus palsy secondary to clavicular nonunion. Case report and literature survey. *Clin Orthop Relat Res*. 1986(206):219–22.
- [23]Derham C, Varghese M, Deacon P, Spencer N, and Curley P. Brachial plexus palsy secondary to clavicular nonunion. *J Trauma*. 2007;63(4):E105–7.
- [24]Krishnan KG, Mucha D, Gupta R, and Schackert G. Brachial plexus compression caused by recurrent clavicular nonunion and space-occupying pseudoarthrosis: definitive reconstruction using free vascularized bone flap-a series of eight cases. *Neurosurgery*. 2008;62(5 Suppl 2):ONS461–9; discussion 9–70.

- [25]Koss SD, Goitz HT, Redler MR, and Whitehill R. Nonunion of a midshaft clavicle fracture associated with subclavian vein compression. A case report. *Orthop Rev.* 1989;18(4):431–4.
- [26]Andermahr J, Jubel A, Elsner A, Prokop A, Tsikaras P, Jupiter J, et al. Malunion of the clavicle causes significant glenoid malposition: a quantitative anatomic investigation. *Surg Radiol Anat.* 2006;28(5):447–56.
- [27]Duncan SF, Sperling JW, and Steinmann S. Infection after clavicle fractures. *Clin Orthop Relat Res.* 2005;439:74–8.
- [28]Rollo G, Pichierri P, Marsilio A, Filipponi M, Bisaccia M, and Meccariello L. The challenge of nonunion after osteosynthesis of the clavicle: is it a biomechanical or infection problem? *Clin Cases Miner Bone Metab.* 2017;14(3):372–8.
- [29]Depaoli A, Zarantonello P, Gallone G, Di Gennaro GL, Ferrari D, Marchesini Reggiani L, et al. Congenital Pseudarthrosis of the Clavicle in Children: A Systematic Review. *Children (Basel).* 2022;9(2).
- [30]Wiss DA, and Garlich JM. Clavicle nonunion: plate and graft type do not affect healing rates-a single surgeon experience with 71 cases. *J Shoulder Elbow Surg.* 2021;30(3):679–84.
- [31]McKnight B, Heckmann N, Hill JR, Pannell WC, Mostofi A, Omid R, 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(9):1412–7.
- [32]Das A, Rollins KE, Elliott K, Johnston P, van-Rensburg L, Tytherleigh-Strong GM, et al. Early versus delayed operative intervention in displaced clavicle fractures. *J Orthop Trauma.* 2014;28(3):119–23.
- [33]Barlow T, Upadhyay P, and Barlow D. External fixators in the treatment of midshaft clavicle non-unions: a systematic review. *Eur J Orthop Surg Traumatol.* 2014;24(2):143–8.
- [34]Martetschlager F, Gaskill TR, and Millett PJ. Management of clavicle nonunion and malunion. *J Shoulder Elbow Surg.* 2013;22(6):862–8.
- [35]Drosdoweck DS, Manwell SE, Ferreira LM, Goel DP, Faber KJ, and Johnson JA. Biomechanical analysis of fixation of middle third fractures of the clavicle. *J Orthop Trauma.* 2011;25(1):39–43.

- [36]Chen W, Tang K, Tao X, Yuan C, and Zhou B. Clavicular non-union treated with fixation using locking compression plate without bone graft. *J Orthop Surg Res*. 2018;13(1):317.
- [37]Fox B, Clement ND, MacDonald DJ, Robinson M, and Nicholson JA. Plate fixation of midshaft clavicle fractures for delayed union and non-union is a cost-effective intervention but functional deficits persist at long-term follow-up. *Shoulder Elbow*. 2022;14(4):360–7.
- [38]Nourian A, Dhaliwal S, Vangala S, and Vezeridis PS. Midshaft Fractures of the Clavicle: A Meta-analysis Comparing Surgical Fixation Using Anteroinferior Plating Versus Superior Plating. *J Orthop Trauma*. 2017;31(9):461–7.
- [39]Woo SH, Bae JY, Jung SW, Choi MH, and Kang SW. Usefulness of double plate fixation after failed ORIF for clavicle shaft fracture. *Eur J Orthop Surg Traumatol*. 2024.
- [40]Muhlenfeld N, Wagner FC, Hupperich A, Heykendorf L, Frodl A, Obid P, et al. Clavicle Shaft Non-Unions-Do We Even Need Bone Grafts? *J Clin Med*. 2024;13(16).
- [41]van der Burg FA, Baltes TP, and Kloen P. Large segmental defects in midshaft clavicle nonunion treated with autologous tricortical iliac crest bone graft. *Shoulder Elbow*. 2023;15(1):45–53.
- [42]Rollo G, Vicenti G, Rotini R, Abate A, Colella A, D'Arienzo A, et al. Clavicle aseptic nonunion: is there a place for cortical allogenic strut graft? *Injury*. 2017;48 Suppl 3:S60–S5.
- [43]Chiang J, Karunaratne YG, Romeo P, Sim ITM, Graham D, and Sivakumar B. Vascularized Bone Reconstruction for Recalcitrant Clavicular Nonunion: A Systematic Review of the Literature. *Ann Plast Surg*. 2025;94(2):229–35.
- [44]Barret H, Mas V, Boissinot T, Baltassat A, Mansat P, and Bonneville N. Satisfactory results in five patients with septic clavicle nonunion using the modified Masquelet technique and structural iliac crest autograft. *JSES Int*. 2024;8(4):734–9.
- [45]Kinami Y, Horita M, Ogasa K, and Fujiwara K. Salvage Surgery for a Recalcitrant Clavicular Nonunion Using the Masquelet Technique: A Case Report. *Cureus*. 2025;17(2):e78990.