Clinical case
https://doi.org/10.18019/1028-4427-2025-31-3-380-387

A series of clinical observations of the treatment of patients with atrophic nonunion and defects of the clavicle midshaft managed with free fibular autografting, the Ilizarov mini-fixator and an intramedullary wire

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Abstract

Introduction Atrophic nonunion and defects is a rare complication of clavicle fractures. Therefore questions arise when choosing the optimal method of their treatment.

Purpose We aimed to retrospectively assess the effectiveness of treating atrophic clavicle midshaft nonunion and defects with a free fibular autologous graft fixed with the Ilizarov mini-fixator in combination with an intrameduallary wire.

Materials and methods A retrospective study of 14 patients (11 females, 3 males) in the mean age of 34.1 ± 2.8 years with atrophic nonunion and defects of the clavicle was carried out. Eleven patients had post-traumatic nonunion after failures of its surgical treatment including seven cases of multiple surgeries, and three cases were congenital nonunion. Pain in the clavicle area was the main complaint in 13 patients. Five had minor restrictions in the shoulder joint function, and two had a pronounced adduction contracture of the shoulder joint. Surgical treatment included debridement, resection of the ends of the fragments to the paprika sign, defect plasty with a free autologous fibular graft followed by combined fixation with an intramedullary wire and the Ilizarov mini-fixator. Supportive compression of 1 mm every two weeks was produced at the junction of the fragments in order to stimulate repair. The mini-fixator was removed after radiographic confirmation of a continuous union of the graft with the fragments.

Results and discussion The post-resection defect averaged 3.1 ± 0.2 cm. Union was achieved in 11 cases. The average period in the mini-fixator was 159.9 ± 11.9 days. In all cases, after dismantling the device, the range of motion in the shoulder joint retained preoperative parameters. The complications were one graft migration, soft-tissue inflammation and deep infection (two cases). Soft-tissue inflammation was treated with antibiotics while deep infection required prompt debridement. Long-term results were followed in 13 patients. There were no problems with the donor site in the long term. The Ilizarov mini-fixator assisted by an intramedullary wire provides stable fixation and allows compression at the junction of bone fragments with a fibular autograft to stimulate bone formation and union in clavicle midshaft nonunion and defects.

Conclusion The combination of three technical components (autologous grafting, Ilizarov mini-fixator, intramedullary wire) yields positive results in the management of large post-resection defects of the clavicle midshaft. Upon graft consolidation, the clavicle acquires a near-to-normal radiographic bone structure.

Keywords: clavicle midshaft, nonunion, bone defect, free fibular grafting, mini-Ilizarov apparatus, intramedullary fixation

For citation: Kolchin SN, Mokhovikov DS, Malkova TA. A series of clinical observations of the treatment of patients with atrophic nonunion and defects of the clavicle midshaft managed with free fibular autografting, the Ilizarov mini-fixator and an intramedullary wire. *Genij Ortopedii*. 2025;31(3):380-387. doi: 10.18019/1028-4427-2025-31-3-380-387.

INTRODUCTION

Clavicle fractures account for 2 to 5 % and up to 10 % of fractures in adult and paediatric population, respectively, and therefore are a frequent practice for an orthopaedic surgeon [1]. The middle third of the clavicle is affected in 80 %. It can be effectively treated conservatively [1–3]. However, non- or mal-union of the clavicle were reported in up to 15 % of conservatively treated displaced fractures [2–5]. Therefore, unstable and open clavicle fractures, displaced fractures and with pronounced shortening or threat of skin perforation continue to require surgical treatment [3–5]. Currently, the main surgical techniques for clavicle fracture repair are plating and intramedullary osteosynthesis, resulting in nonunion rates ranging from 2.6 to 5.9 % [4–8]. It is difficult to assess a direct relationship between surgery and incidence of nonunion. However, it is obvious that inaccurate reduction and instability of fixation can be considered as factors provoking nonunion.

Autologous iliac crest grafting in combination with either plating or nailing are the most common surgical methods for clavicle nonunion [9, 10]. Fragment end layer and the need for a wide dissection of tissues in clavicle nonunion are undoubted problems for achieving union with these techniques. Donor site morbidity after collection of a tricortical graft is a negative consequence. External fixation in the treatment of clavicle nonunion is not a unified approach, and has not been used for extended defects [6, 11–14]. Vascularized grafting, as reported, requires precision techniques, experienced plastic surgeons, and is very traumatic for the donor site [14, 15].

Treatment failure is always a challenging problem that encourages surgeons to search for the most appropriate way of treating clavicle nonunion, including recalcitrant cases [14]. To date, the approach to surgical treatment of clavicle nonunion and defects is not standardized but external fixation has been discussed both for fractures and hyper- /hypotrophic nonunion of the clavicle [6, 16].

We **aimed** to retrospectively assess the effectiveness of treating atrophic clavicle midshaft nonunion and defects with a free fibular autologous graft fixed with the Ilizarov mini-fixator in combination with an intrameduallary wire.

MATERIAL AND METHODS

From 2011 to 2022, fourteen patients (11 females, 3 males) with clavicle nonunion and defects were treated with free autologous fibular grafting and combined fixation with the Ilizarov mini-fixator and an intramedullary wire (Table 1). Their mean age was 34.1 ± 2.8 years (range, 12–53 years). All patients had been previously treated surgically at other hospitals with various methods. The nonunion was post-traumatic after operations for closed fractures in 11 patients. The disease duration ranged from one to 24 years. Three youngest patients had presumably congenital pseudarthrosis of the clavicle diagnosed at the age of over 10 years. They started feeling pain or deformity while growing but their medical records had no history of trauma. Seven patients had more than one intervention for nonunion. One patient had a history of deep infection with remission for more than one year (Table 1, P7) but active signs of inflammation were not diagnosed at admission both by clinical examination and laboratory tests.

Pain of varying intensity was the main complaint in 13 patients. Preoperative examination assessed the range of motion (ROM) in the shoulder joint and radiographic views in two projections. ROM was full in seven patients. Five had a slight restriction in shoulder abduction (up to 30 degrees of total ROM), and two had a pronounced joint motion limitation.

Table 1

Patient data

Patients	P1	P2	P3	P4	P 5	P 6	P7	P 8	P9	P10	P11	P 12	P13	P 14	Means or %
Age	12	20	49	19	16	30	38	53	36	39	51	44	39	44	34.1 ± 2.8 years
Gender	F	F	F	F	F	M	F	F	F	F	M	M	F	F	76.8 % F
Etiology	CP	IF	IF	CP	CP	IF	MVA	MVA	MVA	IF	IF	MVA	MVA	IF	
Duration of the disease (years)	12	2	2	6	9	3	1	1	1	1	24	1	4	9	5.4 ± 1.2
Previous surgery	IW	PL IW	PL IW EF	EF	EF	PL IW	PL PL+ BG	PL PL+ BG	EF	PL	2 PL PL+ BG	PL PL+ BG	IW	IW	7 recalcitrant
Bone defect (cm)	2	2	1.5	2	2.5	4	2.5	4.5	3.5	3.5	3.5	3.5	3	5	3.1 ± 0.2
Surgery time (min)	205	180	180	120	245	175	105	100	145	125	130	100	180	185	155.4 ± 10.0
Consolidation	+	+	–	–	+	+	–	+	+	+	+	+	+	+	78.6 %
Duration of fixation (days)	144	216	183	123	124	168	183	105	121	166	178	163	147	175	159.9 ± 11.9
Follow-up (years)	1	1	1	1	1	1	0.5	1.5	1	1	1	1	5	9	Long-term 92.9 %
Complications	–	BGM	PI	PTI	PTDI	–	DI	–	–	–	–	–	–	DSP	35.7 %

Notes: P — patient; MVA — motor vehicle accident; IF — isolated fracture; CP — congenital pseudarthrosis; IW — intramedullary wire; PL — plating; BG — bone grafting; EF — external fixator; BGM — bone graft migration; PI — pin instability; PTI — pin tract infection; PTDI — pin tract deep infection; DI — deep infection; DSP — donor site pain

The size of the defect was measured in frontal and axial radiographs, the hypotrophy of the fragments was assessed, and the resection of the endplates was planned (Fig. 1 a).

Surgical technique and postoperative care

An anterior approach to the clavicle was used with a patient lying in the supine position. After the removal of foreign bodies and debridement of the interfragmentary gap, resection of nonunion endplates was performed to the bleeding bone (paprika sign) and the fragment ends were shaped for a side-to-side contact with the graft. The length of the defect was measured. The wound was tamponed.

The ipsilateral lower limb was chosen for graft harvesting, what facilitated the work of the surgical team. The fibula was approached in the middle third, retreating proximally at least 10 cm from the ankle joint gap, and a vibrating saw was used for cutting the graft. After hemostasis, the wound was sutured. Primary co-aptation of the graft was assisted by inserting a 1.8-mm intramedullary wire. Depending on the anatomical features of the fragments (defects caused by metal implants), the wire exited from the acromial or sternal end of the clavicle. The wound was sutured.

Three 1.5-mm cantilever wires were inserted in each fragment of the clavicle (Fig. 1 b). The wires passed through both cortical plates. The moment of exit from the cortex was felt as a "fall"; therefore, the pressure on the drill was weakened when passing the second cortical plate. The penetration of the wire into the soft tissues outside the second cortex was no more than 1 to 2 mm. The topography of the neurovascular bundle was necessarily considered. The wires were held at an angle of 90–100° to each other, depending on the soft tissues. The external part of the wires was bent using a wire holder and mounted on the threaded rod of the Ilizarov mini-apparatus. The rod was positioned along the axis of the clavicle and along the projection of the intramedullary wire. Proximally, washers could be used in order to maximize the stability of the support. The distal support was attached to a connection plate in order to enable axial compression (Fig. 1 b).

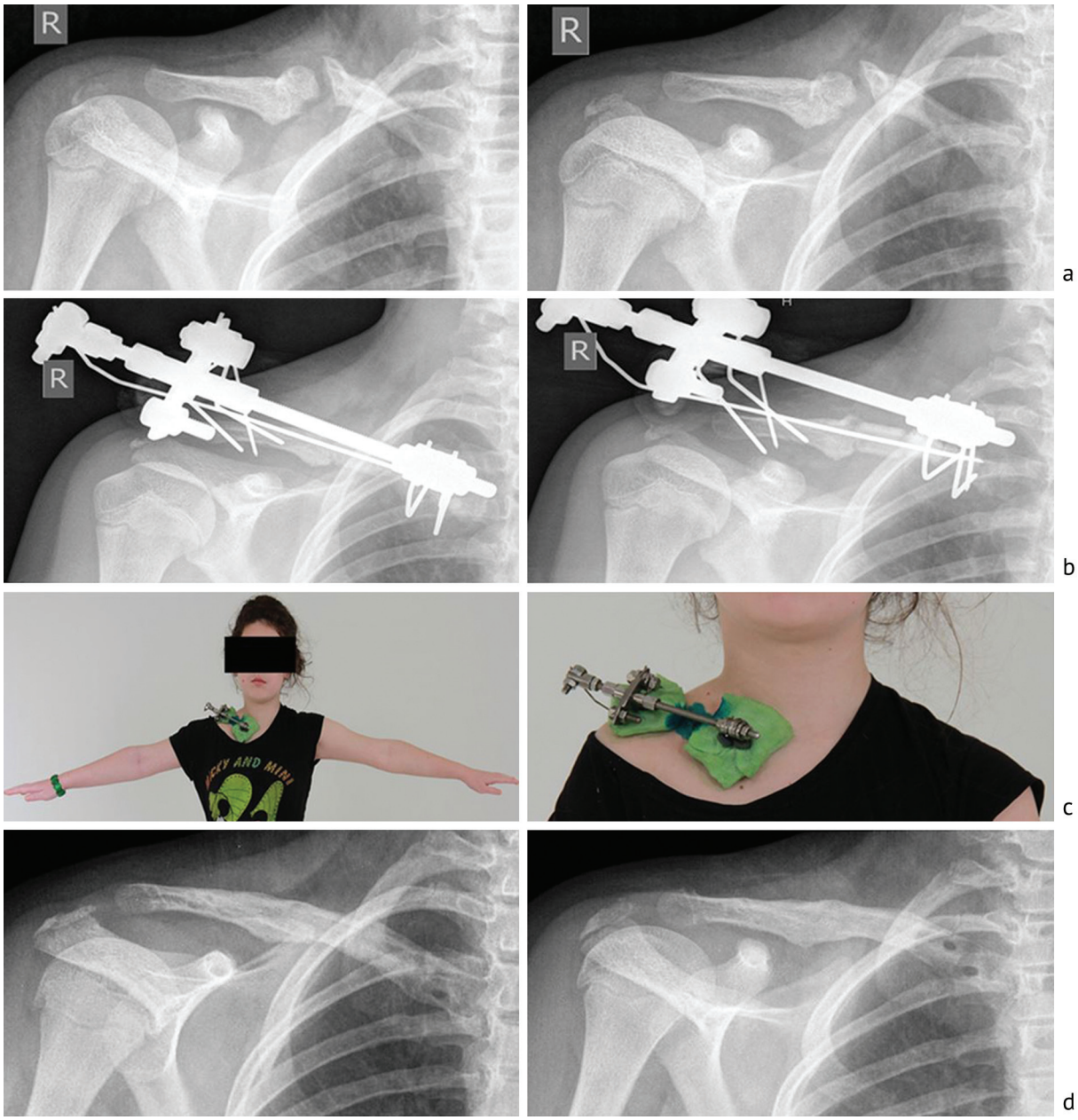

Fig. 1 X-rays and photo of P1 (Table 1) with hypotrophic nonunion of the clavicle with a 5-mm gap and incongruent sclerotic ends of the fragments (a); defect repair and deformity correction upon mini-fixator placement and tight contact of the graft with the fragments (b); photo of the patient showing the shoulder function which is slightly restricted due to the placed mini-fixator (c); union and graft remodeling after 1-year (d)

In the postoperative period, dressings were changed if required. Supportive compression of 1 mm was produced every two weeks. Radiographic checks were taken after 2 and 4 months, further radiographic assessment was recommended based on the consolidation dynamics after 5 and 6 months post-surgery. In the case of the radiographic signs of graft lysis in the contact area, acute compression up to 2–3 mm was performed for tighter contact of the fragments. Exercise therapy was initiated on the first postoperative day with the upper limb fixed in a scarf bandage that was prescribed for at least three months after the operation (Fig. 1 c).

RESULTS

The size of the defects varied from 1.5 to 5 cm and averaged 3.1 ± 0.2 cm after resection. Union was achieved in 11 cases (78.6%) and an average consolidation time was somewhat over 4 months (Table 1). Failures in union were patients 3, 4 and 7. In patient 3, union of the graft was achieved

with only the proximal fragment. The device was removed due to wire instability. Re-osteosynthesis was recommended, but the patient was lost for further treatment. Patient 4 had the device removed due to pin-tract infection; a second osteosynthesis procedure was proposed after infection arrest but the patient was lost for repeated treatment due to a change in his residence place. In patient 5, pin-tract infection developed into deep infection with the need for surgical debridement, after which it was arrested and nonunion healed. Case 7 had a history of chronic infection and this was one of the reasons for infection recurrence. After three months, a fistula opened in the projection of the graft; there were radiographic signs of sequestration, what required surgical debridement but the patient rejected further surgical treatment.

Among other complications was graft migration in patient 2 as instability of the intramedullary wire developed due to marginal defects and bedsores from the previous metal implant. Migration was diagnosed in the early postoperative period while producing compression. This required revision intervention with changing the intramedullary wire. Pain at the donor site was observed in patient 14. The patient fell with her foot twisted on the 7th day after surgery. Pain persisted in the area of the ankle joint but radiography did not reveal any ankle fracture. In the long-term follow-up period, the patient did not complain, radiological signs of ankle joint osteoarthritis were not detected.

In all cases, after fixator removal, the passive ROM in the shoulder joint was within the preoperative ROM and the patients were referred for physiotherapy rehabilitation.

DISCUSSION

Despite the severity of the condition, it is difficult to consider clavicle nonunion and defects a common pathology as the nonunion rate following clavicle fractures is not high [1–7]. Pain, shortening, deformity and limitation of shoulder ROM that accompany nonunion and defects of the clavicle make surgical treatment mandatory. The success rate after primary treatment of nonunion with various methods of osteosynthesis is quite high [6, 9, 10]. Therefore, there is not much experience in treating its failures, and comparative and prospective studies on the topic are unlikely in the future. Our study was a retrospective series of 14 cases collected within a relatively long period of eleven years due to the rarity of the pathology. Moreover, the cases were failures of nonunion treatment with common methods at other facilities. Therefore, based on our retrospective experience of clavicle surgery for nonunion treatment failures, we are inclined to opine that the tactics of treating clavicle nonunion and defects should choose the method of autologous grafting and a fixator that is capable of maintaining stability over a long period of time required for graft remodeling [10, 11].

The Ilizarov mini-fixator that was designed for small bones is capable to produce stable bone fixation, compression and distraction [12, 17, 18]. While planning a revision operation, it is also necessary to consider such negative factors as a history of polytrauma, unstable fixation, multiple interventions, and blood supply disorders at the ends of fragments.

Intramedullary nailing has been successfully used for treating clavicle nonunion. However, the optimal category for this kind of intervention is patients who had no previous surgical treatment [10]. The lack of rotational stability of this fixation method, in our opinion, is a significant drawback. On the other hand, nailing seems more reasonable than plating due to a complex three-dimensional anatomy of the clavicle. It was the reason for the use of an intramedullary reinforcement wire in the technique described by us.

Undoubtedly, bone plating has sufficient fixation capability. However, the surgeon may encounter difficulties in positioning the screws as previous implants leave their tracts in the clavicle. Moreover, compression in the area of the junction with the fragments could be produced once only

during the intervention to install the plate. There were also problems with postoperative wound healing by using wave plating [9]. AO plates used as external fixators cannot allow compression in the postoperative period [11]. The removal of the plate will always require additional surgical intervention and this intervention is associated with the risk of refracture if a structural graft is used. Good results were obtained with double plating [19], but the sample was relatively small. Unfortunately, our study also features this limitation.

It was assumed that external fixation appears to be a reasonable treatment option in hypertrophic nonunion of the clavicle but not in the atrophic one [6]. In our series of atrophic nonunion, an important merit of the Ilizarov mini-fixator was utilized which its ability to produce supportive compression. The technique seems reasonable for marginal aseptic lysis of the graft in the areas of contact with the clavicle fragments, diagnosed by radiographic checking. Thus, additional surgical plasty with bone chips would not be required. To produce compression would be enough to approximate the fragments to the graft. The intramedullary wire in our technique allows such compression without the risk of secondary displacement of the graft. For cortical defects in the fragments caused by previous implants, we recommend paying close attention to stable insertion of the intramedullary wire as it should provide necessary fixation of the graft. The cantilever wires do not pass through the graft and do not hinder its periosteal blood supply. As wide dissection of soft tissues to insert the wires into the fragments is not required, their periosteal blood flow remains preserved and certainly has a positive effect on achieving union [9, 10, 20]. The variability of Ilizarov mini-fixator assemblies allows the inclusion of half-pins, as in AO mini-fixators [13]. Therefore, this external fixator can be used in adult patients with increased body weight. On the other hand, the technology can be used in children and adolescents with small clavicle sizes as insertion of 1.5–1.8-mm wires will not splinter the bone. Given the lack of consensus on the treatment of congenital nonunion of the clavicle [21, 22], the described technique, in our opinion, has shown its possible application in children despite the difficulties with the wire and mini-fixator care in terms of their compliance with asepsis. Other advantages of the Ilizarov mini-fixator include the ease of its dismantling and the possibility to start physiotherapy exercises early [12].

Undoubtedly, cancellous bone from the iliac crest can be considered the "gold standard" of bone grafting. Its use for cases of a small interfragmentary gap, marginal defects in the fragments, or combined with osteoperiosteal decortication leads to good outcomes [9, 11, 19]. However, the iliac crest is a spongy graft, and the closure of a segmental defect of the tubular bone with it requires samples with 2–3 cortical plates and its harvesting may result in donor site pain. On the contrary, the diameter of the fibular graft is close to the diameter of the clavicle and its adaptation in the zone of contact of fragments does not require additional time or complex techniques. The advantages of a fibular graft include its reinforcing properties due to the cortical structure and a medullary canal, which facilitates the insertion of an intramedullary wire. Pain at the donor site level occurred only in one of our cases and was associated with a concomitant injury of the ankle joint ligaments in the early postoperative period. Conservative treatment proved to be effective and the patient had no complaints in the long term.

Moreover, our technique does not require precision equipment, is relatively simple and affordable in contrast to vascularized bone grafting [14, 15]. Moreover, the technique is sufficiently safe. There were no cases of neurovascular problems, brachialgia or injury to the pleura in our clinical cases, similar to other studies with the application of mini-fixators to manage clavicle nonunion [12, 13]. There were two patients who developed deep infection, including the one with its history. It was recently reported that revision surgery after failed surgical treatment of midshaft clavicle fractures is often associated with positive detection of bacteria but without signs of infection [23, 24].

One could judge our technique being a complex procedure due to its three-component structure and possible wire-tract infection. Other techniques that ensured union in recalcitrant cases with resection defect within 1.5 cm are also complex and took longer time to heal [24]. We developed our technology that provides stability and compression mainly for failures of clavicle nonunion treatment accompanied by larger defects or for congenital cases, being aware of the atrophic condition of the fragments ends. Finally, only two cases after multiple previous surgeries did not heal.

Randomized controlled trials would be a valuable contribution to the problem but unfortunately their implementation could hardly be realized.

CONCLUSION

The combination of three technical components (autologous free fibular grafting, Ilizarov mini-fixator, intramedullary wire) provides control of the graft by mechanical compression and consolidation in the management of large postresection defects of the clavicle midshaft. Upon graft consolidation, the clavicle acquires a near-to-normal radiographic bone structure. The upper limb recovers its functionality.

Conflict of interest *The authors have no potential conflicts of interest regarding this manuscript.*

Funding *The authors received no financial support for the preparation, research, and publication of this manuscript.*

Ethical approval *is not required for the presentation of a case series.*

Informed consent *There is no information in the presented work that could be used to identify patients.*

REFERENCES

1. Morgan C, Bennett-Brown K, Stebbings A, et al. Clavicle fractures. Br J Hosp Med (Lond). 2020;81(7):1-7. doi: 10.12968/hmed.2020.0158.
2. Burnham JM, Kim DC, Kamineni S. Midshaft Clavicle Fractures: A Critical Review. Orthopedics. 2016;39(5):e814-21. doi: 10.3928/01477447-20160517-06.
3. Gordienko II, Sakovich AV, Tsap NA, et al. Treatment tactics in pediatric clavicle fractures. Genij Ortopedii. 2021;27(1):13-16. doi: 10.18019/1028-4427-2021-27-1-13-16.
4. 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(5):739-46. doi: 10.1016/j.jse.2015.09.029.
5. Eisenstein ED, Misenhimer JJ, Kotb A, et al. Management of displaced midshaft clavicle fractures in adolescent patients using intramedullary flexible nails: A case series. J Clin Orthop Trauma. 2018;9(Suppl 1):S97-S102. doi: 10.1016/j.jcot.2017.06.019.
6. Barlow T, Upadhyay P, Barlow D. External fixators in the treatment of midshaft clavicle non-unions: a systematic review. Eur J Orthop Surg Traumatol. 2014;24(2):143-148. doi: 10.1007/s00590-013-1173-6.
7. 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(13):1119-1125. doi: 10.2106/JBJS.M.00607.
8. Zlowodzki M, Zelle BA, Cole PA, et al. Treatment of acute midshaft clavicle fractures: systematic review of 2144 fractures: on behalf of the Evidence-Based Orthopaedic Trauma Working Group. J Orthop Trauma. 2005;19(7):504-507. doi: 10.1097/01.bot.0000172287.44278.ef.
9. Marti RK, Nolte PA, Kerkhoffs GM, et al. Operative treatment of mid-shaft clavicular non-union. Int Orthop. 2003;27(3):131-135. doi:10.1007/s00264-002-0424-7.
10. Wu CC, Shih CH, Chen WJ, Tai CL. Treatment of clavicular aseptic nonunion: comparison of plating and intramedullary nailing techniques. J Trauma. 1998;45(3):512-516. doi: 10.1097/00005373-199809000-00014.
11. Kerkhoffs GM, Kuipers MM, Marti RK, Van der Werken C. External fixation with standard AO-plates: technique, indications, and results in 31 cases. J Orthop Trauma. 2003;17(1):61-64. doi: 10.1097/00005131-200301000-00010.
12. Demiralp B, Atesalp AS, Sehirlioglu A, et al. Preliminary results of the use of Ilizarov fixation in clavicular non-union. Arch Orthop Trauma Surg. 2006;126(6):401-5. doi: 10.1007/s00402-006-0137-2.
13. Lodhi IA, Russell R, Sharp DJ, Shah KY. The treatment of non-union of the clavicle with the AO mini external fixator. Surgeon. 2007;5(6):335-338. doi: 10.1016/s1479-666x(07)80085-0.
14. Jaloux C, Bettex Q, Levadoux M, et al. Free vascularized medial femoral condyle corticoperiosteal flap with non-vascularized iliac crest graft for the treatment of recalcitrant clavicle non-union. J Plast Reconstr Aesthet Surg. 2020 Jul;73(7):1232-1238. doi: 10.1016/j.bjps.2020.03.018.
15. Lenoir H, Williams T, Kerfant N, et al. Free vascularized fibular graft as a salvage procedure for large clavicular defect: a two cases report. Orthop Traumatol Surg Res. 2013;99(7):859-863. doi: 10.1016/j.otsr.2013.06.004.
16. Özkul B, Saygılı MS, Dinçel YM, et al. Comparative Results of External Fixation, Plating, or Nonoperative Management for Diaphyseal Clavicle Fractures. Med Princ Pract. 2017;26(5):458-463. doi: 10.1159/000481865.
17. Kolchin SN, Mokhovikov DS. Method of replacing a clavicle defect. Patent RF, no. 2807898, 2023. Available at: https://www.fips.ru/registers-doc-view/fips_servlet?DB=RUPAT&rn=6788&DocNumber=2807898&TypeFile=html. Accessed Jan 24, 2025.

18. Zhang J, Yin P, Han B, et al. The treatment of the atrophic clavicular nonunion by double-plate fixation with autogenous cancellous bone graft: a prospective study. J Orthop Surg Res. 2021;16(1):22. doi: 10.1186/s13018-020-02154-y.
19. Tomori Y, Nanno M, Sonoki K, Majima T. Minimally Invasive Corrective Osteotomy with the Ilizarov Mini-Fixator for Malunited Fractures of the Phalanges: Technical Note. J Nippon Med Sch. 2021;88(3):262-266. doi: 10.1272/jnms.JNMS.2021_88-314.
20. Tomić S, Bumbasirevic M, Lesić A, Bumbasirević V. Modification of the Ilizarov external fixator for aseptic hypertrophic nonunion of the clavicle: an option for treatment. J Orthop Trauma. 2006;20(2):122-128. doi: 10.1097/01.bot.0000197548.84296.2f.
21. Borzunov DY, Mitrofanov AI, Kolchev OV. Treatment of clavicular pseudoarthroses. Genij Ortopedii. 2006;(2):74-77. (In Russ.).
22. Der Tavitian J, Davison JN, Dias JJ. Clavicular fracture non-union surgical outcome and complications. Injury. 2002;33(2):135-143. doi: 10.1016/s0020-1383(01)00069-9.
23. Depaoli A, Zarantonello P, Gallone G, et al. Congenital Pseudarthrosis of the Clavicle in Children: A Systematic Review. Children (Basel). 2022;9(2):147. doi: 10.3390/children9020147.
24. Assouto C, Bertoncelli CM, Gauci MO, et al. Congenital pseudarthrosis of the clavicle: a systematic review. Int Orthop. 2022;46(11):2577-2583. doi: 10.1007/s00264-022-05470-6.
25. Hemmann P, Brunner J, Histing T, Körner D. Revision surgery after failed surgical treatment of midshaft clavicle fractures is often associated with positive detection of bacteria. Arch Orthop Trauma Surg. 2023;143(7):4133-4139. doi: 10.1007/s00402-022-04669-x.
26. Grewal S, Baltes TP, Wiegerinck E, Kloen P. Treatment of a Recalcitrant Non-union of the Clavicle. Strategies Trauma Limb Reconstr. 2022;17(1):1-6. doi: 10.5005/jp-journals-10080-1544.

The article was submitted 27.12.2024; approved after reviewing 21.01.2025; accepted for publication 31.03.2025.

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