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Original Article

Autologous non-vascularized fibula with compression plating in the management of aseptic complex non-union of long bones

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Abstract: Background: The surgical treatment of non-union of long bones are challenging especially when bones are osteoporotic or there is a large bone gap due to repeated surgeries and implant failures. Plate with intramedullary fibula provides a stable construct as fibula acts as a second implant with better anchorage and high pull-out strength. The aim of our study is to present our experience of treating complex non-union of long bones using compression plating (LCP_s/DCP_s) in combination with autologous non-vascularized fibular graft (ANVFG). Material and Methods: 10 cases of complex non-union of long bones (tibia, femur, humerus) treated with debridement, decortication followed by intramedullary fibular strut grafting and rigid osteosynthesis by LCP_s/DCP_s were included in this study. DASH score and LEFS score was used for upper limb and lower limb functional assessment. Results: All patients had clinico-radiological union with a mean time of 11.4 months. Pre-operative mean DASH and LEFS score was 45.9±2.1 and 20.6±2.03 At the last follow-up, mean DASH and LEFS score was 19.8±1.1 and 60.6±2.6. Conclusion: Compression plating with ANVFG is a viable option for treating complex non-union of long bones. Intramedullary fibula acting as a second implant provides mechanical stability and support biological healing with its osteogenic property at the non-union site.

Keywords: Complex non-union, fibula strut graft, long bones, aseptic non-union, compression plating

Introduction

Although post-traumatic and surgical complications have received a lot of attention in recent decades, treating non-union continues to be one of the most problematic cases for orthopaedic surgeons [1]. According to published estimates, the prevalence of non-union has ranged from 5 to 30% [2]. The frequency of open long bone fractures has been rising due to an increase in road traffic accidents (RTAs), which in turn has increased the frequency of complex non-union [3]. Treatment for complex non-union of long bones following failed osteosynthesis is challenging, particularly in the presence of disuse osteoporosis, osteolysis as a result of implant failure, and substantial bone loss [4]. These patients typically require repeated surgeries to stabilise their condition or to remove an infection that is causing soft tissue scarring and the devitalization of any remaining bones. Their care is made more difficult by the indolent infection that nearly usually coexists with deformity, soft tissue atrophy, joint contracture, and limb length disparity [3]. The goal of treating a long bone non-union is to restore the function, painlessness, alignment, and lack of infection in the affected limb. Exchange nailing, open reduction internal fixation with DCP (dynamic compression plate) or LCP (locking compression plate), with or without bone grafting and external fixator, are among the various surgical methods that have been reported [5, 7]. With 92-100% healing rates, autologous non-vascularized fibular graft (ANVFG) combined with compression plating produced good outcomes [23]. The aforementioned structure strengthens long bones mechanically and offers biological stability for gaps and atrophic non-union [6]. Therefore, in this series, we discuss our experience managing surgically treated complex non-union of the

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long bones utilising a combination of LCP/DCP and ANVFG.

Material and methods

Study design

The complex non-union of long bones was the subject of this retrospective study conducted at our centre from January 2018 to December 2021. For this investigation, institutional ethical committee approval was obtained. Every patient gave their informed consent. Patients were tracked down by looking for operated cases of repeatedly operated long bones non-union in our hospital record register between 2018 and 2021. To make sure there were no missing data, we also looked through the Operation Theatre Record Register. A complex non-union was defined as something that met one or more of the following requirements and had been established for at least six months: A non-union site infection, a bone gap larger than 4 cm with atrophic bone ends, and at least one unsuccessful surgical attempt to create union are the criteria.

Inclusion and exclusion criteria

The inclusion criteria were a) established aseptic non-union of long bones which fulfils the criteria ofcomplex type, b) skeletal maturity (>18 years of age), c) willing to give informed consent, d) minimum 2 years of follow-up. Patients having infected non-union, pathological fracture, congenital limb deformities, non-union following periprosthetic fracture, non-union after conservative treatment and uncontrolled systemic comorbidities were excluded.

Data collection and measuring tools

Based on the aforementioned inclusion criteria, our study included a total of 10 cases of complex aseptic non-union cases including the tibia, femur, and humerus that were treated with LCP/DCP in addition to ANVFG. Clinico-radiological diagnosis of non-union was made. Radiographs, in general, were used to identify non-union. Pre-operative data included the patients' clinical characteristics, demographic information, and prior surgical records. To determine the likelihood of infection, the patients' complete blood count (CBC), erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP) values were obtained. From the patient's old data (before surgery), the pattern of severity of fractures and soft tissue injury were categorised using the AO/OTA and Gustilo Anderson classification system [24]. At the time of presentation, all patients had eventual atrophic non-union. During the examination, the patients had abnormal bony mobility, minor pain, and tenderness at the non-union site, which limited their ability to do daily activities. Five patients exhibited visible deformities that could be corrected clinically, including one each in the arm, two in the thigh, and two in the leg. To varied degrees, all patients had stiffness in their ankle, knee, elbow, and shoulder. No additional cancellous grafting procedures were tried.

Surgical techniques

A 32-year-old female who had undergone one operation in the previous two years showed us his most recent x-ray, which revealed implant breakage with non-union of the distal $1/4^{th}$ of femur (**Figure 1**). Another patient with atrophic gap non-union of the mid $1/3^{rd}$ shaft tibia presented 15 months after sustaining injury with one failed prior surgery (**Figure 2**). In every instance, combined spinal epidural anaesthesia (CSEA) was used throughout the operation. The standard surgical approach or the surgical scar from the previous treatment was used to expose the non-union site. After removing any dead or devitalized bone and fibrous tissue, a 4.5 mm drill bit was used to gain entry to the medullary canal.

Medullary canal preparation: the medullary canal was prepared to receive the bone graft. In order to insert the graft, the medullary canal was evenly enlarged both proximally and distally by curettage, a drill, and hand reamers (8-11 mm) to remove fibrous and pseudoarthrosis tissues as well as loose bone pieces.

The fibular graft was prepared by harvesting it using a lateral approach and a torniquet on the ipsilateral side. The centre third of the fibula was used to harvest the graft, ensuring that at least 7 cm of bone was preserved both proximally and distally. The harvested graft was between 10 and 15 cm in length. Before using an osteotome and bone saw to complete the osteotomy, many drill holes were produced at the required level both proximally and distally. Extreme caution was used to locate and protect

Figure 1. 32-year female with open (grade 2) injury to the right knee after RTA. A. X-ray showed comminuted fracture distal 1/4th femur with intercondylar extension. B. Open reduction and dual plating were done. C, D. X-ray at 15 months showed non-union with implant failure. E, F. Implant removed and non-union site was freshened causing shortening of distal fragment. G. Fixation done with Intramedullary fibula and 11-hole LCP. H. X-ray at 1 year showed complete union. I, J. Knee range of motion at 1 year follow-up.

the superficial peroneal nerve. To allow for future trimming, the extra length of the fibular graft was excised. In order to telescope the graft tightly into the canal across the fracture site, it was trimmed. To make sure the graft will be one size smaller than the last reamer used, the graft diameter was measured. It was bevelled at one or both ends if the thickness prevented it from being used.

Insertion of the fibular graft: the graft's centre was marked to make sure it was at the fracture level. To ascertain the precise length that requires trimming, the graft was put into each of the fracture fragments. It was verified that the graft could be readily moved over the prepared medullary canal after subsequent shaping. The fracture was reduced in distraction and the graft was pushed up all the way proximally. The fibula was gradually pushed distally to make sure that both fragments had the same length of graft. Next, the fracture was manually compressed as much as possible.

Plate fixation and achieving compression at the fracture site: fixation was done with 10-11 hole

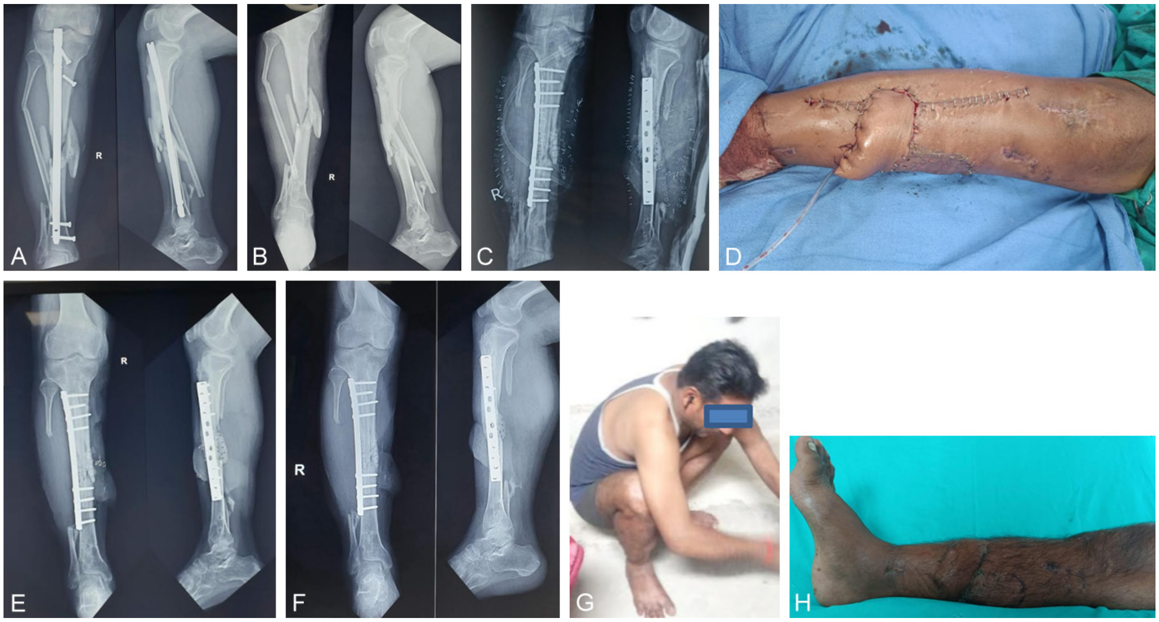

Figure 2. 42 year/male, with injury to right leg (grade 3B). He was managed with tibial interlocking nail (TIN) after 3 days of injury (immediate post. Operative x ray not available). Patient presented to us 15 months after injury. A. X ray at presentation showed gap non-union of mid 1/3rd tibia with TIN in situ. B. TIN was removed and long leg slab given for 1 month. C, D. He was managed with intramedullary fibula from ipsilateral side with DCP along with rotational flap cover and split thickness skin graft in the same sitting. E. Follow-up x-ray at 2 months showed union in progress. F. X ray at 1 year showed complete union. G, H. Knee ROM at 2 years follow-up.

4.5 mm LCP/DCP. As we did not have Muller's device for compression, we choseto compress by DCP holes. We fixed screw on one side of the fracture and under C-arm guidance we went beyond the end of the fibula to put other DCP screw. It was made sure that at least one ± two screws were inserted in each fragment passing through fibular graft in addition to parent bone cortex.

Post-operative protocol and follow-up

Exercises for range of motion (ROM) were initiated the day following the procedure. Until complete fracture union was achieved, patients were followed up with every two months after the first six turns of monthly visits. Weight bearing and weight lifting were not allowed to resume until three to four months after surgery. X-rays were taken at every follow-up to evaluate the fracture union. Fracture healing was taken into consideration on the basis of x-rays, if the bridging callus was visible in three of the four cortices on the antero-posterior and lateral views. Clinical union was characterised by a full weight-bearing walk without pain and the lack of tenderness at the non-union site. Lower extremity functional scale (LEFS) scores [26] and disability of the arm, shoulder, and hand (DASH) scores [27] were used to evaluate functional outcome.

Statistical analysis

Continuous variables were shown as mean ± SD, whereas categorical variables were presented as numbers and percentages. The student t-test was used to compare quantitative variables. Statistical significance was attained when the *p*-value was less than 0.05. The analytical process involved entering the data into an MS Excel spreadsheet and utilising the Statistical Package for Social Sciences (SPSS) version 20.0.

Results

This study comprised ten patients who met the criteria for complex non-union after osteosynthesis failed. The mean age of the nine males and one female was 35.6 years. There were three humeral, three tibial, and four femoral non-unions in all. There were nine RTAs and one fall from height (FFH) as the modes of injury. Among all patients, there were three smokers, three patients had type 2 diabetes mellitus and one had severe osteoporosis. According to the AO/OTA classification, three patients had type A, four had type B, and three had type C fractures. According to the Gustilo Anderson classification, six patients had open fractures and four had closed fractures. In three patients, the non-union site was proximal 1/3rd, in five patients it was mid 1/3rd, and in two patients it was distal 1/3rd and distal 1/4rd.

Four patients had undergone two surgical interventions, while six individuals had undergone one. 15.9 months was the average amount of time spent in non-union. In the past, two patients had plastic surgery procedures (one rotational flap cover and one split thickness skin graft) to cover wounds while one had rotational flap cover in the same sitting at the time of non-union surgery. There was a 5 to 50 mm bone gap. All patients had their ESR and CRP levels checked, and the results were normal. Every patient had a minimum of two years of follow-up. Clinical and radiological union was present in every patient. At the union site, no patient has reported any pain. 11.4 months was the average time to union (range: 9-20 months).

Clinical measurements revealed that the average shortening of the arms was 7 mm (range: 5 to 12 mm), while the average shortening of the legs and thighs was 16 mm (range: 15-20 mm) and 14 mm (range: 9 to 20 mm). **Table 1** displays the demographics of the patients, surgical indications, risk factors, and complications, whereas **Table 2** shows the functional outcomes. At the last follow-up, the DASH score and LEFS improved from the pre-operative averages of 45.9±2.1 and 20.6±2.03 to an average of 19.8±1.1 and 60.6±2.6 ($P<0.05$), indicating that all patients had returned to nearly typical pre-injury activity levels. When compared to the normal side, there was a 20 degrees reduction in both shoulder abduction and flexion. For the elbow and knee, the typical range of motion was 15 to 110 and 25 to 100 degrees, respectively.

Two patients who underwent surgery for distal tibial non-union had plantar flexion from 0 to 20 degrees and no dorsiflexion at all in their ankle joint. At the last follow-up, every patient expressed satisfaction with the treatment. Debridement and oral antibiotics were used to treat one patient who had superficial wound infection. There were no documented problems at the donor site.

Discussion

Long bone non-union following several operations and recurrent implant failure are refractory conditions. They are typically linked to a very poor quality of life in terms of health [25]. The course of treatment is complicated and frequently difficult [8]. In these situations, the bone is frequently osteoporotic and has a wide gap between bone pieces; as a result, any type of surgery may have challenging healing or unfavourable outcomes. Non-union of long bones is most likely related to the type of fracture, the interposition of soft tissues, and the primary fixation's quality [9]. The inability of the bone to successfully unite after surgery may be caused by osteopenia, devitalized bone, poor bone contact, and insufficient stabilisation. Moreover, treatment methods, diabetes mellitus, obesity, smoking, and alcohol abuse may all be contributing factors [10].

We have presented our experience on ten cases of difficult non-union of long bones that failed due to the general and local causes listed above. In these individuals, the choice of surgical treatment is further complicated by osteoporosis resulting from either secondary metabolic causes or from inactivity [8]. These patients frequently had cortical ballooning, scalloping next to screws, metallic debris, and implant breakage. This presents a challenge in the realm of reconstructive procedures thus increasing the chance of implant failure. Although a number of approaches have been previously discussed in the literature for the treatment of complex non-union of long bones, no perfect technique has yet been described [5].

Complex non-union of long bones have been treated with a variety of surgical techniques, including exchange nailing, nail-plate complex, compression plating alone, illizarov, one or two stages of the masquelet technique, cancellous bone grafting, pedicle bone transfer, periosteal free flap transfer, and bone morphogenic protein (BMP) [11]. It has been noted that atrophic/oligotrophic non-union and a bone gap more than 5 mm were risk factors for exchange nailing failure [12]. Moreover, if the nail that has already been put is the maximum

Table 1. Patient's characteristics

Case	Age (years)/Sex (M/F)	Non-union site	AO/OTA classification (1st surgery)	GA classification (1st surgery)	Number of prior procedures	Duration of non-union	Time to union	Complication	Notes	Risk factors
1	32/M	Femur (distal$^{1/4)}$	C	2	1	12	5	None		DM
2	36/M	Femur (mid$^{1/3)}$	C	3A	1	18	6	None	Earlier graft cover	Smoking
3	42/M	Tibia (mid$^{1/3}$)	C	3B	2	24	8	None	Rotational flap cover with split thickness skin graft	DM
4	26/M	Humerus (prox.$^{1/3}$)	B	Closed	1	24	10	None	-	DM
5	34/M	Humerus (mid$^{1/3}$)	B	1	2	9	12	None	-	Smoking
6	40/M	Tibia (distal$^{1/3}$)	A	3B	1	16	8	Superficial infection	Severe osteoporosis and gap, rotational flap cover	Osteoporosis
7	30/M	Tibia (prox$^{1/3}$)	B	Closed	1	20	9	None	-	-
8	37/M	Femur (prox.$^{1/3}$)	A	Closed	2	14	7	None	-	-
9	36/M	Femur (mid$^{1/3}$)	A	Closed	2	12	9	None	External fixator followed by nail applied before and removed	Smoking
10	43/F	Humerus (mid$^{1/3}$)	B	2	1	10	10	None	-	-

Table 2. Statistical analysis of functional outcome

Patients	Pre-operative (LEFS/DASH)	Post-operative (LEFS/DASH)	*p*-value
1	18.8	62.6	<0.05
2	22.4	58.7	
3	21.6	64.4	
4	46.4 (DASH)	18.9	
5	48.2 (DASH)	21.4	
6	24.1	57.3	
7	19.2	62.8	
8	20.6	61.4	
9	17.9	57.1	
10	43.1 (DASH)	19.2	

LEFS, Lower extremity functional scale; DASH, Disabilities of arm, shoulder and hand.

diameter that the manufacturer has marketed, there is no way to exchange it for one that is larger [13]. The nail-plate combination process requires advanced technical skills. Nail in-situ correction of angular deformity is challenging [14]. Furthermore, putting bi-cortical screws through the plates having retained nail is difficult [15]. Long treatment period is necessary for bone transport with Ilizarov/LRS, which may be uncomfortable. Its adoption was further hampered by cosmetic concerns, the need for a second treatment to remove the frame, and the time it took to regain function after the frame was removed [16]. As modern plating techniques have evolved, compression plating seems to be a promising treatment for non-union of long bones. Bellabarba et al. [17] reported using compression plating with DCPs to successfully treat 23 cases of aseptic femoral non-union. When treating non-union of the long bones in the upper and lower limbs, Ramoutar et al. [18] discovered a high union rate with compression plating.

Nevertheless, segmental bone abnormalities were not included in any of these researches. Fundamental to the process of plate osteosynthesis is compression. DCPs are said to have a high union rate for that reason. It corrects axial malalignment and applies compression at the fracture site. It is only applicable, though, when bone quality is appropriate. Given that the majority of difficult non-union cases have poor bone quality and screw purchase as a result of prior implant failure, LCP may be a good choice in these situations [19]. As a result, we decided to do fracture fixation and stabilisation with LCPs/DCP_s. The use of intramedullary fibular strut grafts in conjunction with quadricortical plating was first proposed by Wright et al. [20]. The purpose of this improved mechanical setup is to reduce the risk of fixation failure or fibrous non-union caused by excessive movement or osteoporotic bone conditions. This approach prevents considerable donor site morbidity, in contrast to iliac crest bone graft (ICBG), which lacks intrinsic mechanical strength until fracture union. We chose to add fibular grafts to our case series in every instance in order to increase the construct's structural integrity. In none of the patients did we employ iliac crest graft. Our approach avoids purposeful shortening, utilizing non-vascularized fibula, which is easily harvested with minimal graft site morbidity and does not necessitate proficiency in microsurgical skills. Following fixation, the cortical bone guarantees swift structural continuity and stability.

The fibula functions like a triflanged nail, firmly attaching itself to the host bone and making it the best donor for reconstructing long bone defects [21]. We saw no cases of graft resorption or failure, which surprised us because cortical bone grafts frequently fail because of insufficient vascularity from surrounding soft tissues. Compared to surgical options such as allografts, external fixator-assisted bone transfer, induced membrane technique, and bone morphogenetic proteins, using autografts with fibula is a significantly more economical method. Even though the benefits of autologous non-vascularized fibular graft versus allogenic or vascularized alternatives are still up for debate, we think it's a very good option, especially in areas with weak bone banking systems and a scarcity of physicians with microsurgical training.

Hence, the utilization of fibular autograft in this technique is anticipated to gain widespread acceptance as a dependable procedure viable at most centers, particularly in healthcare systems where patients directly bear the costs. While a potential theoretical drawback of autologous non-vascularized fibular grafts (ANVFG) involves the disturbance of both periosteal and endosteal blood supply, it's essential to note that donor site morbidity is a recognized disadvantage, albeit often minimal [6, 22]. Non-vascularized fibular grafts, when used freely, carry a known risk of necrosis, leading to absorption and non-incorporation into the host bone. Nevertheless, studies have indicated that the survival of autologous bone grafts can be ensured if they are promptly affixed to the recipient's bone upon retrieval. The osteogenic qualities of the graft are preserved when it is immediately fixed at the recipient location, which makes it easier for the cells on and inside the graft to absorb oxygen and nutrients from the bloodstream [6]. In ourseries, the favourable outcomes with minimal complications endorse the adoption of this straightforward and dependable alternative.

The present study bears noteworthy limitations. It is a retrospective case series involving a restricted patient cohort conducted at a single center with constrained resources (absence ofallograft) and overseen by a single surgeon. Our method greatly improves patient compliance while simultaneously restoring function to the non-united atrophic complex non-union, which makes our study strong. This minimizes the need for prolonged and expensive treatments like the illizarov method, known for frustrating outcomes, while ensuring pain free extremity functionat its fullest potential.

Conclusion

In conclusion, using a Dynamic/Locking Compression Plate (DCP_s/LCP_s) in conjunction with an autologous non-vascularized fibular strut graft has proven to be a reliable option for managing "complex" non-union situations that include significant bone loss and osteopenia. Additional mechanical stability is provided by the addition of a free fibular graft, especially in cases of osteoporotic bone disease. Very little reduction in the length of the host bone was seen, which allowed for an early mobilisation and a good union. This work offers a practical substitute for treating complicated long bone non-union.

Disclosure of conflict of interest

None.

Abbreviations

DCP, Dynamic compression plate; LCP, Locking compression plate; ANVFG, Autologous non-vascularized fibular graft; ROM, Range of motion; LEFS, Lower extremity functional scale; RTA, Road traffic accident.

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References

[1] Bolkvadze S, Avazashvili N, Nozadze T and Tomadze G. Cortical intramedullary fibular graft in surgical treatment of long bones nonunion. Georgian Med News 2019; 11-15.

[2] Zura R, Xiong Z, Einhorn T, Watson JT, Ostrum RF, Prayson MJ, Della Rocca GJ, Mehta S, McKinley T, Wang Z and Steen RG. Epidemiology of fracture nonunion in 18 human bones. JAMA Surg 2016; 151: e162775.

[3] Seenappa HK, Shukla MK and Narasimhaiah M. Management of complex long bone nonunions using limb reconstruction system. Indian J Orthop 2013; 47: 602-7.

[4] Shetty K, Cheppalli N and Kaki D. Autologous nonvascularized fibula graft and locking compression plating for failed fixation of humeral shaft with atrophic gap nonunion. Cureus 2022; 14: e24293.

[5] Ding P, Chen Q, Zhang C and Yao C. Revision with locking compression plate by compression technique for diaphyseal nonunions of the femur and the tibia: a retrospective study of 54 cases. Biomed Res Int 2021; 2021: 9905067.

[6] Yadav SS. The use of a free fibular strut as a "biological intramedullary nail" for the treatment of complex nonunion of long bones. JB JS Open Access 2018; 3: e0050.

[7] Kilic A, Arslan A, Mutlu H, Cetinkaya E, May C and Parmaksizoglu AS. Fibular non-vascularized graft might be a practical solution for treatment of osteopenic humeral shaft nonunion in elderly obese patients. Journal of Academic Research in Medicine 2011; 1: 15-17.

[8] Tanna DD, Gawhale S, Shinde K, Gondalia V, Park H and Shyam AK. Intramedullary fibula with rigid osteosynthesis in revision of neglected and multiple times operated non union of long bones. Trauma International 2017; 3: 27-31.

[9] Castellá FB, Garcia FB, Berry EM, Perelló EB, Sanchez-Alepuz E and Gabarda R. Nonunion of the humeral shaft: long lateral butterfly fracture--a nonunion predictive pattern? Clin Orthop Relat Res 2004; 227-230.

[10] Pascarella R, Ponziani L, Ferri M, Ercolani C and Zinghi GF. Aseptic nonunion of the humeral shaft. Chir Organi Mov 2000; 85: 29-34.

[11] Dimitriou R, Dahabreh Z, Katsoulis E, Matthews SJ, Branfoot T and Giannoudis PV. Application of recombinant BMP-7 on persistent upper and lower limb non-unions. Injury 2005; 36 Suppl 4: S51-9.
[12] Tsang ST, Mills LA, Frantzias J, Baren JP, Keating JF and Simpson AH. Exchange nailing for nonunion of diaphyseal fractures of the tibia: our results and an analysis of the risk factors for failure. Bone Joint J 2016; 98-B: 534-541.
[13] Nadkarni B, Srivastav S, Mittal V and Agarwal S. Use of locking compression plates for long bone nonunions without removing existing intramedullary nail: review of literature and our experience. J Trauma 2008; 65: 482-486.
[14] Wang Z, Liu C, Liu C, Zhou Q and Liu J. Effectiveness of exchange nailing and augmentation plating for femoral shaft nonunion after nailing. Int Orthop 2014; 38: 2343-2347.
[15] Said GZ, Said HG and el-Sharkawi MM. Failed intramedullary nailing of femur: open reduction and plate augmentation with the nail in situ. Int Orthop 2011; 35: 1089-1092.
[16] Tomić S, Bumbasirević M, Lesić A, Mitković M and Atkinson HD. Ilizarov frame fixation without bone graft for atrophic humeral shaft nonunion: 28 patients with a minimum 2-year follow-up. J Orthop Trauma 2007; 21: 549-556.
[17] Bellabarba C, Ricci WM and Bolhofner BR. Results of indirect reduction and plating of femoral shaft nonunions after intramedullary nailing. J Orthop Trauma 2001; 15: 254-263.
[18] Ramoutar DN, Rodrigues J, Quah C, Boulton C and Moran CG. Judet decortication and compression plate fixation of long bone non-union: is bone graft necessary? Injury 2011; 42: 1430-1434.
[19] Hierholzer C, Sama D, Toro JB, Peterson M and Helfet DL. Plate fixation of ununited humeral shaft fractures: effect of type of bone graft on healing. J Bone Joint Surg Am 2006; 88: 1442-1447.
[20] Wright TW. Treatment of humeral diaphyseal nonunions in patients with severely compromised bone. J South Orthop Assoc 1997; 6: 1-7.
[21] Willis MP, Brooks JP, Badman BL, Gaines RJ, Mighell MA and Sanders RW. Treatment of atrophic diaphyseal humeral nonunions with compressive locked plating and augmented with an intramedullary strut allograft. J Orthop Trauma 2013; 27: 77-81.
[22] Kashayi-Chowdojirao S, Vallurupalli A, Chilakamarri VK, Patnala C, Chodavarapu LM, Kancherla NR and Khazi Syed AH. Role of autologous non-vascularised intramedullary fibular strut graft in humeral shaft nonunions following failed plating. J Clin Orthop Trauma 2017; 8 Suppl 2: S21-S30.
[23] Karadeniz S and Bolukbasi M. Functional outcomes of patients treated with fibula strut graft and double plate in the treatment of recalcitrant humerus nonunions. Mid Blac Sea Journal of Health Sci 2022; 8: 393-402.
[24] Gustilo RB and Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am 1976; 58: 453-8.
[25] Schottel PC, O'Connor DP and Brinker MR. Time trade-off as a measure of health-related quality of life: long bone nonunions have a devastating impact. J Bone Joint Surg Am 2015; 97: 1406-1410.
[26] Dingemans SA, Kleipool SC, Mulders MAM, Winkelhagen J, Schep NWL, Goslings JC and Schepers T. Normative data for the lower extremity functional scale (LEFS). Acta Orthop 2017; 88: 422-426.
[27] Gummesson C, Atroshi I and Ekdahl C. The disabilities of the arm, shoulder and hand (DASH) outcome questionnaire: longitudinal construct validity and measuring self-rated health change after surgery. BMC Musculoskelet Disord 2003; 4: 11.