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# Enhancing Bone Union in Aseptic Femoral Shaft Nonunion by Multimodal Autologous Bone Graft and Mechanical Stabilization

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**Abstract**

Aseptic femoral shaft nonunion represents a biologically compromised state in which impaired osteogenesis, insufficient vascularity, and inadequate mechanical stability prevent healing. Although mechanical revision is essential, achieving union often requires effective autologous bone tissue transplantation and biologic stimulation. This study evaluated a multimodal revision strategy integrating structural and cancellous autografts with mechanical reconstruction to restore both biological viability and stability at the nonunion site. Fifty-four patients with aseptic femoral shaft nonunion were retrospectively reviewed. Revision procedures included exchange nailing, augmentation plating with retained nail, plate replacement, or dynamization. All biologic strategies were based on autologous bone transplantation, including iliac crest cancellous bone grafting, cortical onlay strut grafts harvested from the iliac crest, and Judet osteoperiosteal decortication to enhance local vascularity. Union was assessed based on clinical and radiographic criteria during follow-up. The overall union rate was 96.3% (52/54). Hypertrophic and oligotrophic nonunions achieved

100% union, whereas atrophic nonunions achieved 83.3%. Both exchange nailing and augmentation plating resulted in 100% healing. The most favorable outcomes were observed in patients receiving combined autologous bone grafting (cancellous autograft ± cortical strut graft) together with Judet decortication, underscoring the importance of restoring osteogenic potential and biological activity in addition to mechanical rigidity. Multimodal revision combining stable fixation with autologous bone graft transplantation and biologic enhancement provides an effective treatment option for aseptic femoral shaft nonunion. These findings reinforce the principle that addressing biological insufficiency—through cancellous autografting, cortical strut transplantation, and decortication—is essential to achieving successful bone regeneration, particularly in atrophic nonunion.

**Keywords**

Femoral shaft nonunion; autologous bone graft; cortical strut graft; Judet decortication; augmentative plating; exchange nailing; bone grafting

## 1. Introduction

The treatment of femoral shaft fractures has significantly improved with advances in fixation techniques and devices. However, despite these developments, nonunion of the femoral shaft remains a challenging complication after osteosynthesis, with an incidence ranging from 1-10%, depending on fracture type and fixation stability [1].

Managing femoral nonunion is particularly challenging. Failure after revision surgery poses significant technical, psychological, and medicolegal challenges. Therefore, improving the biological environment at the nonunion site and ensuring stable fixation are critical to achieving bone healing.

Several adjunctive procedures have been proposed to stimulate osteogenesis in such cases. Bone marrow injection combined with stable fixation has been shown to achieve union rates of approximately 80-90% in atrophic nonunions [2]. Similarly, autologous cancellous bone grafting remains a reliable technique, with reported union rates of 85-95%, especially when meticulous debridement and rigid fixation are performed simultaneously [3]. Onlay cortical strut grafts used alongside internal fixation have also been reported to provide high rates of union and additional mechanical stability [4]. Moreover, the Judet decortication technique, which involves creating living bone flaps at the nonunion site, has demonstrated union rates exceeding 90% in several reports [5, 6].

These findings suggest that a variety of surgical strategies, when properly executed, can effectively promote bone union in cases of femoral nonunion. Nevertheless, no single technique consistently achieves near-universal success. We therefore hypothesized that combining several biological and mechanical methods within a single operative procedure could further enhance osteogenesis and improve overall union rates.

In the present study, we implemented a multimodal surgical approach for femoral shaft nonunion consisting of: (1) Judet-style cortical decortication to create pedicled osteoperiosteal bone flaps; (2) meticulous debridement of the nonunion site followed by grafting with morselized autologous cancellous bone harvested from the iliac crest; and (3) rigid fixation using either intramedullary nailing or plate fixation, further reinforced by (4) onlay cortical strut grafts secured across the nonunion site with cortical screws.

Depending on the pre-existing implant conditions, fixation devices were either retained, exchanged, or converted to a new intramedullary nail or new plate. In several cases, a small anti-rotational plate was additionally applied to augment construct rigidity. The objective of this study was to evaluate bone healing outcomes using this combined multimodal technique.

## 2. Materials and Methods

### *2.1 Study Design and Setting*

A retrospective cross-sectional study was conducted at Cho Ray Hospital, Ho Chi Minh City, Vietnam. Medical records and radiographs of all patients who underwent surgical treatment for aseptic nonunion of the femoral shaft from January 2017 to December 2023 were reviewed.

### *2.2 Patients and Inclusion Criteria*

Eligible patients were aged 16 years or older with a diagnosis of aseptic femoral shaft nonunion following previous osteosynthesis of a femoral shaft fracture.

Inclusion criteria were as follows:

Persistent nonunion for ≥6 months after initial fixation.

Radiological features of nonunion located between the subtrochanteric region and 4-6 cm proximal to the distal femoral condyles.

Absence of clinical or laboratory evidence of infection.

Patients were excluded if they had segmental bone loss >3 cm, systemic contraindications to surgery (e.g., severe cardiopulmonary disease, uncontrolled diabetes, chronic renal failure), neurological disorders affecting limb function, or inability to comply with follow-up.

### *2.3 Definition of Aseptic Nonunion*

Nonunion was defined as the absence of progressive healing for at least 6 months after initial fixation, accompanied by both clinical signs (persistent pain or instability) and radiographic evidence of non-healing [7, 8]. This definition is consistent with widely accepted orthopedic criteria. Although the U.S. FDA defines nonunion at 9 months, earlier diagnosis at 6 months is commonly adopted in clinical practice when there is no evidence of progression toward union.

Aseptic nonunion was defined based on a combination of clinical, laboratory, and intraoperative findings. Patients were required to have no history suggestive of prior infection (e.g., no wound drainage, sinus formation, or previous surgical site infection), no clinical signs of infection, and normal inflammatory markers (WBC 4-12 × $10^9$/L, ESR < 22 mm/h, CRP < 0.7 mg/dL). In cases with any suspicion of infection, intraoperative tissue samples were obtained for microbiological culture under sterile conditions. In patients with late-presenting nonunion but no clinical or laboratory suspicion of infection, intraoperative cultures were not routinely performed and were left to the discretion of the operating surgeon.

Only cases with no clinical, laboratory, or microbiological evidence of infection were classified as aseptic nonunion and included in the study. In accordance with current concepts in nonunion management, treatment strategies should address both biological viability and mechanical stability [9].

### *2.4 Surgical Technique*

All operations were performed by experienced orthopedic surgeons using a multimodal reconstructive approach designed to enhance both biological and mechanical factors of bone healing. Each patient received at least two of the three bioactive enhancement techniques described below (Figure 1).

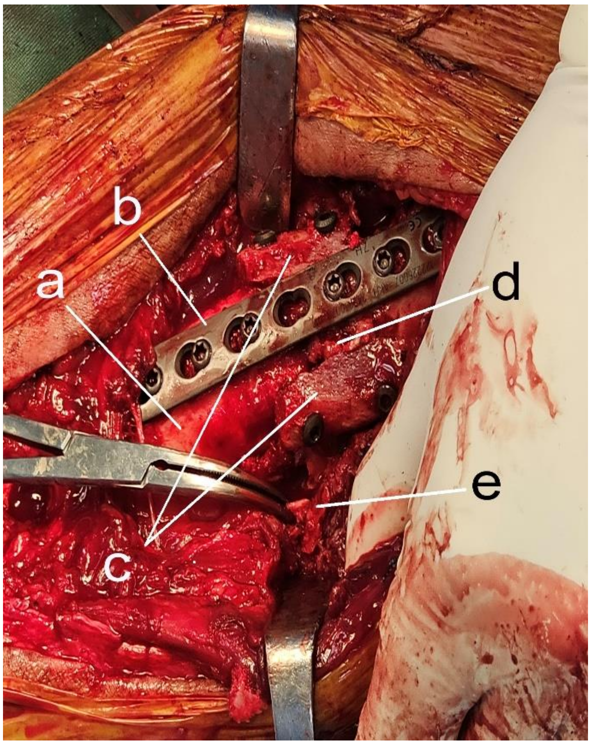


**Figure 1** Multimodal technique for treating femoral shaft nonunion (intraoperative view). a. a femoral shaft nonunion; b. an augmentation plate; c. a pelvic cortical bone onlay graft; d. morselized autologous cancellous bone graft placed in the gap; e. a piece of pedicled bone created by Judet decortication.

The procedure consisted of the following steps:

Judet-style cortical decortication (JCD) creates pedicled osteoperiosteal bone flaps to stimulate local vascularity and enhance biological activity at the nonunion site.

Meticulous debridement of fibrous tissue and sclerotic bone ends, followed by grafting with morselized autologous cancellous bone (MACBG) harvested from the iliac crest, tightly packed into the nonunion gap.

Application of onlay cortical strut grafts (OCSG) across the nonunion site, secured with cortical screws to provide additional mechanical reinforcement and restore bone continuity (Figure 1).

Simultaneously, rigid internal fixation was applied, using either an intramedullary nail or a plate-and-screw construct. In selected cases, the existing fixation device was retained, exchanged, or converted to achieve optimal stability. When instability was suspected, a small anti-rotational plate (augmentation plate) was applied to enhance construct rigidity (Figure 1) further.

Radiographic examples of nonunion and postoperative construct are shown in Figure 2.

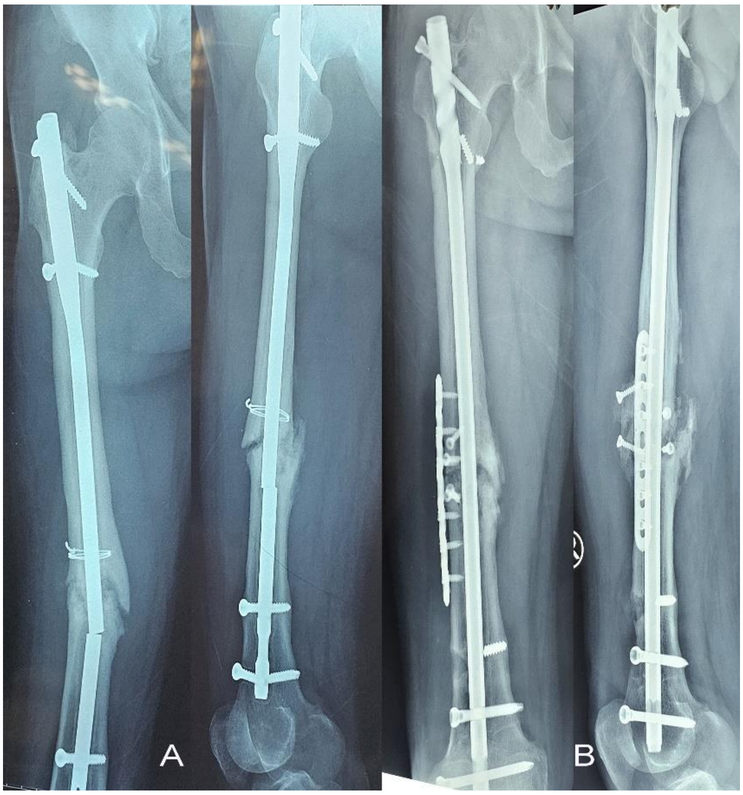


**Figure 2** Radiographic outcome of multimodal technique for femoral shaft non-union. A. preoperative radiograph showing femoral shaft nonunion; B. postoperative radiograph after exchange intramedullary nailing and application of an augmentation plate; three bioactive enhancement techniques were used.

### *2.5 Data Collection and Variables*

Demographic data (age, sex, affected side, fracture level), fracture characteristics, prior fixation type, and surgical details were extracted from hospital archives. Initial injury characteristics, including mechanism of injury and fracture classification (e.g., AO classification), were not consistently available due to the referral nature of the cohort. Therefore, they were not included in the analysis. Donor-site complications were systematically assessed based on clinical follow-up records at each postoperative visit, including pain at the iliac crest, infection, hematoma, and other local complications. Only clinically significant complications documented during follow-up were recorded.

Radiographic classification of nonunion followed Weber-Cech (1976) criteria (hypertrophic, oligotrophic, atrophic) [7].

Postoperative radiographic images were collected (Figure 2).

Clinical and radiographic evaluations were performed until bone union was achieved or treatment failed.

Union was defined as pain-free weight-bearing and bridging callus on ≥3 cortices in orthogonal radiographs.

Failure was defined as persistent nonunion or implant breakage after ≥7 months of follow-up.

### 2.6 Statistical Analysis

Descriptive statistics were used to summarize patient characteristics, surgical techniques, and clinical outcomes. Continuous variables are presented as means with ranges, and categorical variables as frequencies and percentages. Due to the relatively small sample size and heterogeneity in treatment strategies, no formal statistical analysis was performed to compare treatment groups.

### 2.7 Ethics Statement

This retrospective study was approved by the Institutional Review Board of Cho Ray Hospital, Ho Chi Minh City, Vietnam (approval No. 25-25/GCN-HĐĐĐ, April 1, 2025) and was conducted in accordance with the Declaration of Helsinki. Due to the retrospective design and anonymization of patient data, the ethics committee waived the requirement for informed consent.

## 3. Results

### 3.1 Patient Characteristics

Between 2017 and 2023, a total of 4,129 patients with femoral shaft fractures were recorded at Cho Ray Hospital. Among these, 216 cases were identified as femoral shaft nonunion. Of these nonunion cases, 54 aseptic nonunion cases met the inclusion criteria. The mean age of the patients was 39.3 years (range: 16-72 years). Most patients were in the working-age group (21-40 years), accounting for 50% of the cohort. Demographic and clinical data are summarized in Table 1. All patients underwent autologous iliac crest bone grafting, including both cancellous bone grafts and cortical strut grafts.

**Table 1** Demographic and clinical characteristics of the study population.

| Variable | No. of cases | Percentage (%) |
|---|---|---|
| Male | 41 | 75.9 |
| Female | 13 | 24.1 |
| Total | 54 | 100 |
| Age 16-20 | 4 | 7.4 |
| 21-40 | 27 | 50.0 |
| 41-60 | 17 | 31.5 |
| >60 | 6 | 11.1 |
| Proximal third | 13 | 24.1 |
| Middle third | 25 | 46.3 |
| Distal third | 16 | 29.6 |
| Right side | 21 | 38.9 |
| Left side | 33 | 61.1 |

### *3.2 Type of Nonunion and Previous Fixation*

According to the Weber-Cech classification, 48 cases (88.9%) were hypertrophic or oligotrophic, and 6 cases (11.1%) were atrophic. Intramedullary nailing was the most common initial fixation (63%), followed by plating (26%) and other techniques (11%) (Table 2).

**Table 2** Type of nonunion and previous fixation.

| Type of nonunion | Intramedullary nail | Plate | Other | Total |
|---|---|---|---|---|
| Hypertrophic + Oligotrophic | 27 | 13 | 8 | 48 |
| Atrophic | 5 | 1 | 0 | 6 |
| Total | 32 | 14 | 8 | |

### *3.3 Surgical Timing and Follow-Up*

The mean interval between the initial fixation and revision surgery was 11.3 months (range, 6-28 months). The mean follow-up period was 25.3 ± 13 months (range, 6-72 months).

### *3.4 Bone Union Outcomes*

The overall bone union rate was 96.3% (52/54). Union was achieved in all hypertrophic and oligotrophic cases (100%) and in four of six atrophic cases (83.3%).

### *3.5 Union Rate by Surgical Technique*

Depending on the previous fixation, the multimodal revision technique involved Judet-style decortication, morselized cancellous bone grafting, and onlay cortical strut grafts. The overall union rates according to the revision method are shown in Table 3.

**Table 3** Bone union by revision method.

| Revision technique | Cases (n) | Union n (%) |
|---|---|---|
| Augmentation plate | 14 | 14 (100) |
| Exchange nailing | 17 | 17 (100) |
| Plate replacement | 11 | 10 (90.9) |
| Retain or dynamization | 12 | 11 (91.7) |
| Total | 54 | 52 (96.3) |

### *3.6 Detailed Outcomes by Fixation and Grafting Type*

The detailed outcomes according to the type of previous fixation and the multimodal surgical technique are presented in Table 4, Table 5, and Table 6. Each table shows the distribution of cases according to the applied biological and mechanical enhancement procedures, including morselized cancellous bone graft, Judet-style decortication with pedicled bone flaps, and onlay cortical strut grafts (a cortical strut harvested from the iliac crest fixed across the nonunion gap with two screws).

**Table 4** Treatment outcomes in 32 patients with previous intramedullary nail fixation.

| Technique | MACBG + OCSG | MACBG + JCD | MACBG + JCD + OCSG | Union | Nonunion |
|---|---|---|---|---|---|
| Retain devices or dynamization | 3 | 1 | 3 | 7 | 0 |
| Augmentation plate | 2 | 0 | 6 | 8 | 0 |
| Exchange nailing | 5 | 1 | 4 | 10 | 0 |
| Plate replacement | 1 | 0 | 6 | 7 | 0 |

**Table 5** Treatment outcomes in 14 patients with previous plate fixation.

| Technique | MACBG + OCSG | MACBG + JCD | MACBG + JCD + OCSG | Union | Nonunion |
|---|---|---|---|---|---|
| Retain devices | 0 | 0 | 3 | 3 | 0 |
| Plate augmentation | 1 | 1 | 2 | 4 | 0 |
| Exchange nailing | 2 | 0 | 2 | 4 | 0 |
| Plate replacement | 0 | 1 | 1 | 2 | 1 |

**Table 6** Treatment outcomes in 8 patients with previous other fixation methods.

| Technique | MACBG + OCSG | MACBG + JCD | MACBG + JCD + OCSG | Union | Nonunion |
|---|---|---|---|---|---|
| Retain devices | 0 | 1 | 1 | 2 | 1 |
| Plate augmentation | 0 | 1 | 1 | 2 | 0 |
| Exchange nailing | 1 | 1 | 1 | 3 | 0 |
| Plate replacement | 1 | 0 | 0 | 1 | 0 |

In patients with retained or dynamically adjusted intramedullary nails, union was achieved in all seven cases. The combination of Judet decortication and onlay grafts demonstrated the most consistent union results in this group.

In the plate fixation group, the best outcomes were achieved with plate augmentation and exchange nailing, both yielding 100% union rate. One case of nonunion was observed in the plate replacement subgroup.

In cases previously treated with other fixation methods, such as Küntscher nails, DHS, and DC, the multimodal approach also achieved high union rates. Exchange nailing and plate augmentation were associated with excellent outcomes, with only one nonunion recorded in the retained subgroup.

### *3.7 Complications*

Only two cases (3.7%) failed to achieve bone union. Mild, transient donor-site pain at the iliac crest occurred in 5.5% of cases. Postoperative shortening ≤2 cm was observed in the majority of patients and was considered clinically acceptable. Angular or rotational deformity >5° occurred in just one case. Knee flexion ≥120° was preserved in 72.2% of patients, and 96.3% had full extension.

## 4. Discussion

In our cohort, a multimodal revision combining rigid fixation with biological augmentation (Judet-style decortication, cancellous iliac crest bone graft, and selective onlay cortical strut grafts) achieved an overall union rate of 96.3% (52/54). The union rate of 96.3% observed in this study is consistent with previous literature. A meta-analysis by Luo et al. [10] reported a union rate of approximately 73% for exchange nailing and up to 96% for augmentative plating in the treatment of femoral shaft nonunion. The high union rate in the present study is comparable to that of augmentative plating and may be attributed to the consistent application of a biological and mechanical approach across all cases. Within revision strategies, augmentation plating and exchange nailing each reached 100% union rate, whereas plate replacement and retain/dynamization yielded 90.9% and 91.7%, respectively. These findings frame two key questions addressed below.

### *4.1 Revision Fixation Methods Associated with the Highest Union Rate*

In this series, both augmentative (supplementary) plating and exchange nailing produced excellent and identical healing—100% union in their respective groups—while plate replacement and retain/dynamization trailed modestly. This pattern is consistent with contemporary evidence. Systematic reviews and comparative studies reporting femoral shaft nonunion after failed intramedullary nailing increasingly favor augmentative plating over exchange nailing, with pooled or reported union rates typically in the mid-90s to near-100% for augmentative plating and a wider, often lower range (≈72-100%) for exchange nailing. Notably, a 2013 systematic review recommended plating after failed nailing and exchange nailing after failed plating; later meta-analyses and comparative series have shown that augmentative plating achieves faster healing and fewer complications than exchange nailing [10, 11] while maintaining very high union rates [10, 12]. Our 100% union rate in both groups likely reflects concurrent biological optimization (routine cancellous autografting, frequent decortication, and selective strut augmentation), which may elevate exchange nailing outcomes to the top of their historical range.

### *4.2 The Bone-Grafting/Biologic Modalities Yield the Highest Union*

All patients in our cohort received autologous cancellous iliac crest bone graft (ICBG), and many also underwent Judet-style decortication and/or onlay cortical strut augmentation. The near-universal union mirrors the literature, in which ICBG remains the reference standard for long-bone nonunion (union commonly ≈ 90-97%). Decortication with plate fixation is repeatedly associated with union rates >90% in long-bone nonunion, including the femur. In oligotrophic/atrophic patterns or mechanically demanding reconstructions, onlay cortical strut constructs (including the dual-strut "sandwich" technique) have demonstrated union rates approaching 100% in focused series. At the same time, biomechanical and clinical data support their role in increasing construct stiffness and providing additional biology. In our practice, combining ICBG with decortication provided a strong baseline of biology; selective addition of onlay struts was reserved for femora with cortical deficiency, a long nonunion gap, or concern for bending/rotational rigidity—scenarios in which the literature suggests struts can be particularly advantageous.

The single nonunion in our series involved a patient with a retained Küntscher nail, treated only with Judet-style decortication and cancellous iliac crest bone grafting, without mechanical reinforcement. This case highlights that biological stimulation alone cannot compensate for insufficient construct stability. The Küntscher nail, an early unlocked design with limited torsional stiffness, provides inadequate control of rotation and bending under femoral loading, predisposing to persistent micromotion and fibrous tissue formation instead of bone bridging.

Numerous studies have emphasized the need to restore both biological and mechanical integrity in the revision of femoral shaft nonunion. Somford et al. [12] reported higher failure rates when unstable fixation was retained despite grafting. Furlong et al. [13] and Ha et al. [14] demonstrated improved outcomes when the nail was exchanged to a more rigid construct. Similarly, Cho et al. [6] and Guyver et al. [5] found that Judet decortication achieved optimal results only when coupled with stable fixation. More recently, Luo et al. [10] and Mohamed et al. [15] confirmed that augmentative plating or exchange nailing markedly enhances union compared with grafting alone.

Therefore, in revision cases using older-generation unlocked nails, mechanical augmentation—either exchange to an interlocking nail or addition of an augmentation plate—should accompany biological enhancement to achieve predictable healing and prevent recurrent nonunion.

### *4.3 Two Nonunion Cases*

Both nonunion cases in our series shared the common feature of insufficient mechanical reinforcement despite adequate biological stimulation. The first involved a retained Küntscher nail treated with Judet-style decortication and only cancellous iliac crest bone grafting. The second underwent plate replacement, but, similarly, only decortication and cancellous grafting were performed without onlay cortical strut augmentation. In both, the absence of improved fixation stiffness likely accounted for the persistent nonunion.

The Küntscher nail, as an early unlocked, slotted design, provides limited torsional and bending rigidity compared with interlocking systems or augmented constructs. Retaining such a nail may allow excessive micromotion at the nonunion site, inhibiting bone bridging despite biological support. Similarly, simple plate replacement without mechanical augmentation offers little improvement in construct stiffness if bone defects, cortical loss, or stress shielding remain. Studies have repeatedly emphasized that rigid fixation and biological enhancement must coexist for successful healing of femoral nonunion. Somford et al. [12] and Luo et al. [10] demonstrated superior outcomes with augmentative plating compared with exchange nailing when mechanical stability was optimized. Cho et al. [6] and Guyver et al. [5] reported that Judet decortication achieved its full benefit only under stable fixation. More recently, Mohamed et al. [15] confirmed that plate augmentation with retained nail achieved union rates approaching 100%, highlighting the value of mechanical synergy.

### *4.4 The Role of Onlay Strut Grafting*

The present findings further support the use of cortical onlay strut grafts as a valuable adjunct in complex femoral nonunions. This technique provides a dual benefit—it enhances local osteogenesis through the biological activity of the graft while simultaneously increasing construct stiffness by acting as an external splint along the femoral cortex. Biomechanically, the strut functions as a tension band, improving both bending and rotational resistance. When combined with intramedullary fixation, the screws anchoring the iliac cortical strut often engage the retained nail, thereby creating an integrated bone-implant construct that markedly strengthens stability at the nonunion site.

Several authors have emphasized these advantages. Aslantürk et al. [4] demonstrated near-complete union rates using the dual-strut "sandwich" configuration, while Judas et al. [16] and Wu et al. [17] highlighted the technique's ability to restore both biological and mechanical integrity in recalcitrant femoral nonunion. Thus, onlay strut grafting should be considered not only a biological procedure but also a mechanical augmentation, particularly beneficial in revision after intramedullary nailing, where additional rigidity is desirable.

### *4.5 Limitations*

This study has several limitations. First, its retrospective design may introduce inherent selection and information bias. Second, the study population consisted of patients referred after prior treatment at different institutions; therefore, detailed information on initial fracture characteristics—such as whether the fracture was open or closed, the degree of soft-tissue injury, and initial management protocols—was not consistently available. Third, the relatively small sample size of patients meeting the inclusion criteria may limit the generalizability of the findings. The absence of comparative statistical analysis between different treatment strategies is another limitation of this study. Smoking status and osteoporosis status were inconsistently recorded in the medical records and, therefore, could not be included in the analysis. The NonUnion Severity Score (NUSS) was not applied due to incomplete data inherent to the retrospective design. Instead, the Weber-Cech classification was used to reflect biological activity at the nonunion site. Additionally, the absence of a control group prevents direct comparison with other treatment strategies. Due to the study's retrospective design and the heterogeneity of prior treatments, a standardized control group could not be established. Therefore, it is not possible to determine whether the observed outcomes are attributable to biological augmentation, mechanical stabilization, or their combination. Despite these limitations, the present study provides valuable clinical insights into the effectiveness of a combined biological and mechanical approach in the management of aseptic femoral shaft nonunion.

## 5. Conclusion

The present study demonstrates that successful management of aseptic femoral shaft nonunion requires the simultaneous restoration of both biological activity and mechanical stability. To ensure predictable healing, surgeons should prioritize rigid and reliable fixation of the nonunion site. When instability or implant fatigue is suspected, the nail or plate should be exchanged rather than retaining suboptimal fixation.

Biological stimulation should also be maximized through a combination of biological techniques. The concurrent use of all three biological techniques—bone grafting, decortication, and onlay iliac crest cortical strut application—offers the best potential for rapid and robust bone union. This integrated strategy, which strengthens both biology and biomechanics, represents the most comprehensive and reliable approach for managing difficult femoral nonunions and preventing recurrent treatment failure.

## Author Contributions

Duong Binh Tran: study design, surgical treatment, supervision, manuscript drafting. Thi Cao: study design, surgical treatment, supervision, manuscript drafting and critical revision. Sinh The Pham: data collection, surgical treatment, radiographic assessment, statistical analysis, manuscript editing. Binh Xuan Luong: study design, surgical treatment, data collection, radiographic assessment. All authors have read and approved the final version of the manuscript.

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## Competing Interests

The authors have declared that no competing interests exist.

## Data Availability Statement

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

## AI-Assisted Technologies Statement

The authors used ChatGPT (OpenAI) to assist in language polishing and editing. Authors take full responsibility for the final manuscript.

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