Indian Journal of Orthopaedics
https://doi.org/10.1007/s43465-024-01205-4

REVIEW ARTICLE

# Management of Distal Femoral Non-union: A Systematic Review

**Filippo Migliorini[1,5] · Luise Schäfer[2] · Francesco Simeone[1] · Abhishek Vaish[3] · Janki Sharan Bhadani[4] · Raju Vaishya[3]**

Received: 23 May 2024 / Accepted: 11 June 2024


## Abstract

**Introduction** Managing distal femur fracture nonunion is complex, with unpredictable results. The present investigation systematically updates current evidence, reviews existing modalities, innovations and related outcomes, and discusses future perspectives on the management of nonunion of the distal femur.

**Methods** This study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the 2020 PRISMA statement. In April 2024, PubMed, Web of Science, Google Scholar, and Embase were accessed without time constraints. No additional filters were used in the database search. All the clinical studies investigating treatment options for nonunion of distal femur fractures were accessed.

**Results** 35 clinical studies (832 patients) were included. Of them, 34.2% (239 of 698 patients) reported an open fracture, and 24.5% (78 of 319 patients) reported infection at the fracture site. The mean length of the follow-up was 28.9 ± 13.2 months. The mean age of the patients was 53.8 ± 14.7 years.

**Conclusion** 84.5% (703 of 832) of patients reached complete union without major complications, and 3.8% (32 of 832) reached complete union with major complications at a mean of 21.7 ± 20.9 months. 8.7% (72 of 832) patients showed signs of persistent non-union.

**Level of evidence** Level III, systematic review.

**Keywords** Distal femoral fractures · Nonunion · Fracture fixation · Fracture healing

## Introduction

Distal femoral fractures account for about 3–6% of all femoral fractures [1–3]. Previously published reviews on distal femoral nonunion have provided valuable insights into the epidemiology, risk factors, and treatment of this condition [4–6]. The distal femoral nonunions, although rare, negatively impact the quality of life (QOL) and pose considerable treatment challenges [7, 8]. Patients with open and comminuted fractures and infections are most prone to develop nonunion [9, 10]. Open reduction and internal fixation (ORIF) combined with cancellous autografting is the most successful treatment option, with a union rate of 97.4% and an average time to heal of 7.8 months [11, 12].

✉ Filippo Migliorini
Filippo.migliorini@sabes.it; migliorini.md@gmail.com

Luise Schäfer
luiseschaefer83@gmail.com

Francesco Simeone
francesco.simeone@sabes.it

Abhishek Vaish
drabhishekvaish@gmai.com

Janki Sharan Bhadani
jsbhadani@gmail.com

Raju Vaishya
raju.vaishya@gmail.com

[1] Department of Orthopaedic and Trauma Surgery, Academic Hospital of Bolzano (SABES-ASDAA), 39100 Bolzano, Italy

[2] Department of Orthopedics and Trauma Surgery, Eifelklinik St. Brigida, Simmerath, Germany

[3] Department of Orthopaedics and Joint Replacement Surgery, Indraprastha Apollo Hospital, New Delhi 110076, India

[4] Department of Orthopaedics, Paras HMRI Hospital, Patna, Bihar, India

[5] Department of Life Sciences, Health, and Health Professions, Link Campus University, Rome, Italy

Published online: 22 June 2024

Several non-modifiable and modifiable risk factors for non-union have been identified, including open fractures, fractures with bone loss, and those associated with osteoporosis, diabetes, obesity, and malnutrition [13, 14]. In addition, certain patient-related factors like smoking, advanced age, and obesity are also considered to affect fracture healing negatively [14, 15]. Importantly, inadequate fracture fixation is primarily responsible for non-union and implant failure [16]. The rigidity score has been advocated to predict the risk of nonunion [17, 18]. This score was significantly associated with the risk of non-union [18]. Still, no significant association was detected between non-union and postoperative weight-bearing status or other previously identified risk factors [17]. Karam et al. [19] reported an overall similar non-union rate of 17.8% in both locked plating of closed periprosthetic and non-periprosthetic distal femoral and comminution, which was the most crucial predictor of non-union.

Although nonunions are a well-known complication of fractures, evidence on this condition is limited. The present investigation systematically updates current evidence, reviews existing modalities, innovations, and related outcomes, and discusses future perspectives on the management of nonunion of the distal femur.

## Methods

### Eligibility Criteria

All the clinical studies investigating treatment options for nonunion distal femur fractures were accessed. According to the author's language capabilities, English, German, Italian, French, and Spanish articles were eligible. Only studies with levels I to V of evidence, according to the Oxford Centre of Evidence-Based Medicine [20], were considered. Reviews, opinions, letters, and editorials were not considered, as were animals, in vitro, biomechanics, computational, and cadaveric investigations. Missing quantitative data under the outcomes of interests warranted the exclusion of the study.

### Search Strategy

This study was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: the 2020 PRISMA statement [21]. The following PICO algorithm was established for the database search:

- P (Problem): nonunion distal femur fractures;
- I (Intervention): management;
- C (Comparison): different modalities of fracture healing;
- O (Outcomes): union.

In May 2024, PubMed, Web of Science, Google Scholar, and Embase were accessed without time constraints. The Medical Subject Headings (MeSH) used for the database search are reported in the Appendix. No additional filters were used in the database search.

### Selection and Data Collection

Two authors (FM and LS) independently performed the database search. All the resulting titles were screened by hand and, if suitable, the abstract was accessed. The full text of the abstracts which matched the topic was accessed. If the full text was not accessible or available, the article was not considered for inclusion. A cross reference of the bibliography of the full-text articles was also performed for inclusion. Disagreements were debated and mutually solved by the authors. In case of further disagreements, a third senior author (RV) decided.

### Data Items

Two authors (FM and LS) independently performed data extraction. The following data were extracted: author and year, name of the journal and study design, level of evidence, length of the follow-up, number of included patients, mean age, percentage of women, type of initial and definitive treatment, time to definitive treatment, number of unions with or without major complications and main findings. Data were extracted in Microsoft Office Excel version 16.72 (Microsoft Corporation, Redmond, USA).

### Assessment of the Risk of Bias and Quality of the Recommendations

The risk of bias was evaluated following the guidelines outlined in the Cochrane Handbook for Systematic Reviews of Interventions [22]. Nonrandomised controlled trials (non-RCTs) were assessed using the Risk of Bias in Nonrandomised Studies of Interventions (ROBINS-I) tool [23]. Seven domains of potential bias in non-RCTs were assessed. Possible cofounding and the nature of patient selection before the start of the comparative intervention are assessed by two domains. A further domain is used to determine bias in the classification during the intervention. The final four domains assess the methodological quality after the intervention comparison has been implemented and relate to deviations from previously intended interventions, missing data, erroneous measurement of outcomes, and bias in the selection of reported outcomes. The figure of the ROBINS-I

was elaborated using the Robvis Software (Risk-of-bias VISualization, Riskofbias.info, Bristol, UK).

### Synthesis Methods

The main author (FM) performed the statistical analyses following the recommendations of the Cochrane Handbook for Systematic Reviews of Interventions [22]. The IBM SPSS software (version 25) was used. For dichotomic data, the number of events and observations were reported. For continuous data, the arithmetic mean and standard deviation were used.

## Results

### Study Selection

The literature search resulted in 179 articles. All search results were extracted and checked for relevance. Of these, 84 studies were discarded because they were duplicates. Following the defined inclusion criteria, the abstracts of 95 articles were reviewed, and 47 studies were excluded because they did not match the eligibility criteria. The reasons that led to exclusion were: study design (N = 28), low level of evidence (N = 2), not evaluating the un-union of distal femur fracture (N = 9), and language limitations (N = 8). An additional 13 articles were excluded because they did not offer quantitative data on the outcomes of interest. In conclusion, 35 investigations were included in the present analysis. The results of the literature search are shown in Fig. 1.

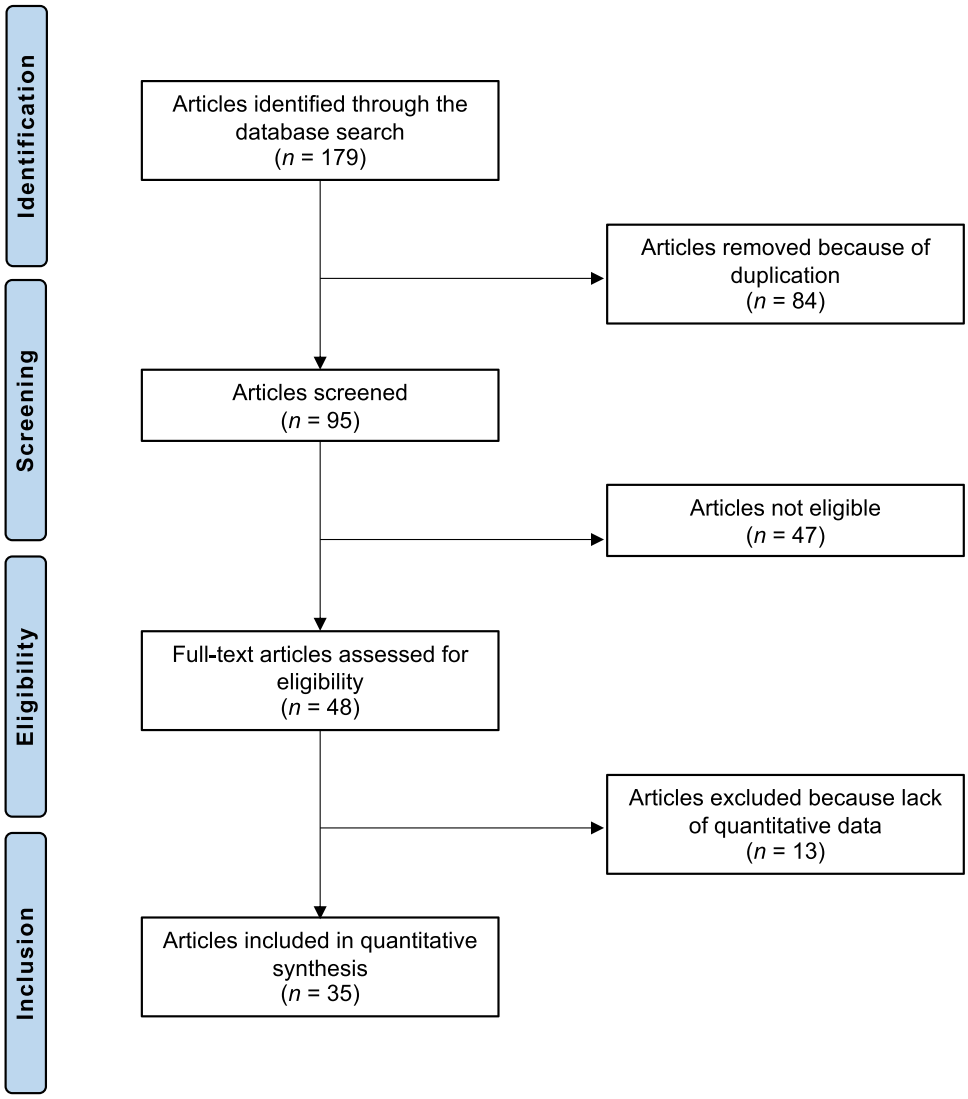


**Fig. 1** PRISMA flow chart of the literature search

### Methodological Quality Assessment

The ROBINS-I was applied to investigate the risk of bias in the included studies. Given the small number of patients studied in the included investigations, the risk of bias based on confounding and the selection of participants was rated in four studies as serious and in four other studies considered critical because they reported data from only one or two patients. The remaining studies were rated as having a low to moderate risk of bias in these domains. The protocol of intervention was well reported in most studies, and no significant deviation from the interventions was identified, leading to an overall low to moderate risk of bias in the classification of interventions and deviation from intended interventions. Data were adequately reported in the most included studies, and the measurement of the outcomes was equivalent among the groups. Given the lack of randomisation of the investigators and patients, the measurement of the outcomes was evaluated with a moderate risk of bias in all of the studies. When described, the reported results corresponded to the planned protocol in most included studies. However, the exact details of a protocol are often missing, leading to a moderate risk of bias in most of the studies. Given the overall poor methodological quality in the included studies, the overall risk of bias was predominantly moderate. The assessments of the methodological quality are given in Fig. 2.

### Study Characteristics and Results of Individual Studies

Data from 832 patients were collected. Of them, 34.2% (239 of 698 patients) reported an open fracture, and 24.5% (78 of 319 patients) reported infection at the fracture site. The mean length of the follow-up was 28.9 ± 13.2 months. The mean age of the patients was 53.8 ± 14.7 years. The generalities, patient characteristics and main results of the included studies are reported in Table 1.

### Result Syntheses

At a mean of 21.7 ± 20.9 months, 84.5% (703 of 832) of patients reached complete union without major complications, and 3.8% (32 of 832) reached complete union with major complications. On the other hand, 8.7% (72 of 832) patients showed signs of persistent non-union.

## Discussion

The present systematic review revealed that with surgical management of the distal femoral nonunion 84.5% (703 of 832) of patients reached complete union without major complications, and 3.8% (32 of 832) reached complete union with major complications at a mean of 21.7 ± 20.9 months. But, 8.7% (72 of 832) patients showed signs of persistent non-union.

Distal femoral nonunions are challenging to manage, and patient risk factors should be critically evaluated when treating acute distal femoral fractures, since several modifiable risks, such as intake of alcohol and steroids, smoking, and diabetic control, might reduce the risk of nonunion [4, 10, 24]. In addition, optimal fracture alignment and compression are also essential when treating acute fractures [25]. Infections are important risk factors, especially in open fractures or fractures that fail to heal [26, 27]. There is good evidence to guide decision-making and successful union with conventional trauma fixation techniques in the majority of patients. Biological augmentation of fracture healing is not necessary in most cases but needs to be considered in higher-risk cases with a mobile atrophic pattern.

The definition of nonunion is heterogeneous and is related to the time elapsed from the injury to the diagnosis

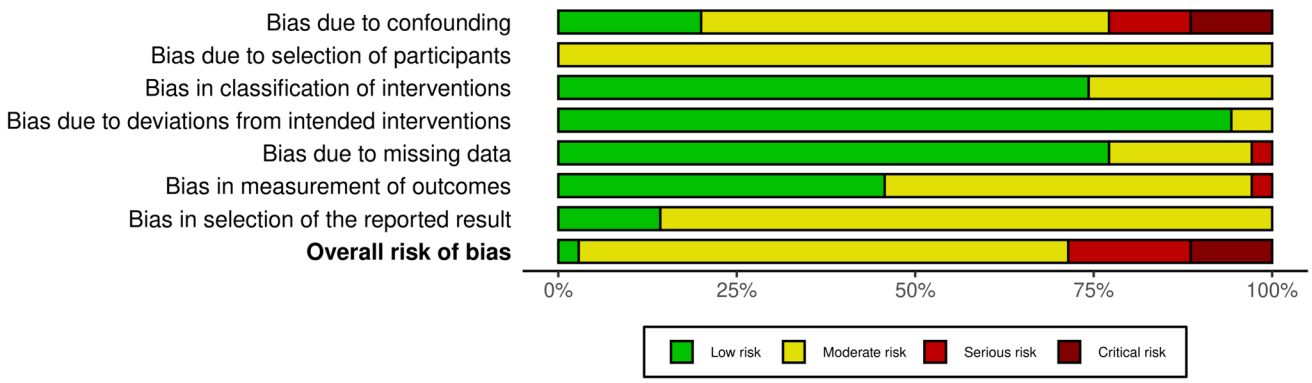


**Fig. 2** The ROBINS-I of non-randomised control trials

**Table 1** Generalities, patient characteristics, and main results of the included studies

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ali & Saleh, 2002 [72] | *Egyptian Orthopaedic Journal* | Retrospective case series | IV | 35.3 | 12 | 41.7 | 0 | | 9 | AO/OTA classification: 33A2 (2) 33A3 (4) 33C2 (6) | DFLP (7) Unilateral external fixator (3) Retrograde IMN (2) | Ilizarov fixator | The Ilizarov EF technique can be used as an effective treatment option with low complications in the management of non-united distal femoral fractures that may be difficult to manage using other means of fixation |
| Ali & Saleh, 2002 [72] | *Injury* | Retrospective case series | IV | 55.2 | 15 | 35.4 | 40 | 9 | 5 | Femoral osteotomy (1) | DCS in (7) Blade plate (7) Retrograde femoral nail (1) | EF | The advantages of preservation of soft tissue, immobilisation of the fracture site by crossing the knee joint and the facility for proximal lengthening make EF definite option in the management of distal femoral nonunions |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alt et al., 2007 [73] | *J Orthop Trauma* | Case Report | V | 24 | 1 | 49 | 0 | 1 | 0 | Left lateral femoral neck fracture<br>Gustilo Anderson grade I<br>Open distal femoral shaft fracture (same side)<br>Comminuted fracture of the left tibia and fibula | EF<br>Angle blade plate | rhBMP-s | rhBMP-2 has the potential to heal nonunions of the femur when combined with stable fixation of the nonunion sites |
| Bellabarba et al., 2002 [74] | *J Orthop Trauma* | Prospective case series | IV | 23 | 20 | 48 | 40 | 7 | 1 | Gustilo and Anderson Type:<br>IIIB (1)<br>IIIA (3)<br>II (3)<br>AO/OTA classification:<br>33-A (11)<br>33-C (9)<br>33-2, 33-3 (8)<br>33-C3 (3) | ORIF (19)<br>Plaster cast (1)<br>Condylar blade-plate (7)<br>DCS (7)<br>Condylar buttress plate (5)<br>DCP(1)<br>Osteoset bone graft substitute (1) | Indirect reduction techniques using the 95-degree condylar blade plate, condylar buttress plate, or locking condylar plate with autologous cancellous bone grafting in 45% (9 of 20) of patients | Contemporary plating techniques are effective in the treatment of distal femoral nonunions. Union occurred reliably with few complications, resulting in a majority of good or excellent clinical results |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chen et al., 2011 [75] | *Chin J Traumatol* | Case Report | V | 15 | 1 | 23 | 0 | 0 | | AO/OTA classification: 33-C2 | 1. ORIF with cloverleaf plate<br>2. Exchanging the cloverleaf plate with an LCP and using the autoiliac bone graft to fill the nonunion gap | Remove of the plate and screws<br>Insertion of IMN<br>Place laterally and medially to the fracture site, drilled two holes respectively, and fastened with suture<br>Auto-iliac bone grafting with nonunion bone grafts | An autologous graft of double strut fibular cortical bone plate is effective in managing long-bone fractures and defects of the lower extremities. This procedure may also be preferable in reconstructing the femur in cases of multiple failures of fracture fixation |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cone et al., 2023 [10] | *J Orthop Trauma* | Retrospective cohort study | III | 27 | 438 | 48 | 47.3 | 168 | | OTA/AO 33A type fractures (108)<br>OTA/AO 33C type fractures (330) | LLP<br>IMN<br>LLP + IMN<br>Ex-Fix | The surgical approach and technique were at the discretion of the operating surgeon and determined by the fracture characteristics | Segmental bone loss, open fractures, chronic anaemia, and increasing body mass index are significant risk factors in the occurrence of distal femoral nonunion. Lateral-locked plating characteristics did not seem to affect nonunion rates |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Davila et al., 2001 [76] | *J Orthop Trauma* | Case Report | V | 24 | 2 | 68 | 100 | 1 | 0 | C3 supracondylar distal femur fracture<br>Open right supracondylar femur fracture | IMN<br>Condylar buttress plate<br>Bone grafting<br>ORIF | TKA with kinematic rotating hinge mega prosthesis | TKA using a mega prosthesis is a good solution for elderly patients with a persistent distal femoral nonunion despite multiple attempts at obtaining union. Patients can expect excellent pain relief and a good range of motion. We do not advocate arthroplasty for an acute fracture since the majority of these fractures do well following internal fixation |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ebraheim et al., 2016 [77] | *Orthop Surg* | Retrospective case series | IV | 29 | 14 | 65 | 92,9 | 1 | 0 | AO/OTA classification: 33-A1 (3) 33-A2 (6) 33-A3 (2) 33-C3 (3) | LCP | ORIF revision (11) Revision without ORIF—only iliac crest stem cell autograft, bone graft substitute, or rh-BMP-2 (3) **Additional to ORIF revision:** rh-BMP-2 (12) Iliac crest bone autograft (5), Iliac crest stem cell autograft (2), Crushed cancellous bone allograft (3), CaSO 4 tricalcium phosphate bone graft substitute (2) demineralized bone matrix (1) Medial plate (2) | Definitive treatment of distal femur nonunion after initial treatment with a locking plate had a low rate of success in this study, suggesting that this procedure is ineffective as a definitive treatment for distal femur nonunion |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gardner et al., 2008 [78] | *J Trauma* | Retrospective case series | IV | 41.5 | 31 | 57.6 | 71 | 4 | 4 | | Plate (1)<br>Ex-Fix (3)<br>Condylar buttress plate (2)<br>DCS (14)<br>DCP (1)<br>Blade plate (4)<br>IMN (2)<br>Ilizarov (1)<br>Allograft (1)<br>Plate and cast (1) | ORIF<br>Debridement of the nonunion<br>Correction of the deformity in the coronal and sagittal planes<br>Bone grafting (100%)<br>Iliac crest bone graft (71%)<br>Demineralized bone matrix (29%)<br>Arthrolysis when necessary<br>Fixed-angle implant and lag screws | Distal femoral nonunions may be treated successfully with correction of deformity, stable fixed-angle internal fixation, lag screw placement, and supplemental bone grafting. Knee joint manipulation and arthrolysis are important components of the treatment plan if knee motion is limited because of fibrosis. This yields predictable functional outcomes after the surgical intervention |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Graves et al., 2005 [79] | *J Orthop Trauma* | Case Report | V | 24 | 1 | 55 | 100 | 1 | 0 | Gustilo and Anderson Type: Type 3C AO/OTA classification: 33A-1 | IMN Debridement anterior iliac crest bone grafting Nail dynamization | The joint procedure with vascular and orthopaedic surgeons: Mobilisation of vessel repair Ligating aneurysmal feeder vessels Bridge plating and iliac crest autograft | The importance of preoperative vascular assessment in the case of nonunions or malunions associated with a previous vascular injury is emphasized |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hailer and Hoffmann, 2006 [80] | *Arch Orthop Trauma Surg* | Case Report | V | 48 | 1 | 82 | 100 | | 0 | AO/OTA classification: 33 A | DCS | LISS plate<br>Autologous bone graft laterally<br>Strut cortical autograft medially | LISS adequately addresses the important aspects of a nonunion fixation of the distal femur in elderly patients.<br>A precise surgical plan may mostly include bone grafting and in selected cases limb shortening.<br>Bone healing and preservation of knee function can be achieved even in severe osteoporosis with substantial bone defects |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Holzman et al., 2016 [81] | *Clin Orthop Relat Res* | Retrospective case series | IV | 18 | 22 | 58 | 72.7 | 8 | 15 | Distal femoral osteotomy (1)<br>Periprosthetic nonunion above a TKA (3) | ORIF with a lateral locking plate (2)<br>ORIF with autogenous bone graft (2)<br>ORIF with allograft and an implanted bone stimulator (1)<br>TKA (3) | Single-stage procedure (16): stable lateral plate involved the addition of an MLP and autogenous bone graft<br>Two-stage treatment (7): lateral plate failure involved placement of a new LLP followed by the addition of a medial locking plate with autogenous bone graft at least 2 months after the first procedure | A very high proportion of patients achieve union when using medial locking plates to treat distal femoral nonunions after lateral plating of the original injury. The addition of bone graft staged reconstruction, and revision of the initial lateral plate is indicated when the nonunion is associated with fatigue failure of the initial lateral plate |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kim et al., 2015 [9] | *Eur J Orthop Surg Traumatol* | Retrospective case series | IV | 48.5 | 22 | 44.3 | 45 | 10 | 22 | AO/OTA classification:<br>A type (7)<br>B type (5)<br>C type (10) | Screws (1)<br>LCP (9)<br>Blade (3)<br>Plate (1)<br>EF (5)<br>Nail (3) | Debridement of the nonunion<br>Autologous bone grafting with or without additional plating<br>Long-term antibiotics if intraoperative cultures were positive | Surgeons should consider indolent infection as a possible cause of nonunion in distal femoral fractures. An intraoperative biopsy tissue culture verifies the presence of indolent infection and antibiotics treatment based on identified organisms leads to successful treatment and better prognosis |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ma et al., 2017 [82] | *Arch Orthop Trauma Surg* | Retrospective case series | IV | 23.4 | 12 | 33 | 41.7 | 7 | 0 | | CBP (6)<br>Nail (3)<br>LCP (2) | Three-stage treatment protocol:<br>Remove hardware and debridement<br>Lengthening of soft tissue<br>Correct alignment<br>Definitive fixation with locked plate<br>Cement spacer<br>Bone defect reconstruction (Masquelet technique or vascularized bone graft) | In conclusion, even though the current study included small sample size and required three stages of intervention, the protocol helped achieve bony union, leg length equality, and normal limb alignment, as well as excellent ambulatory capacity in all cases. Hence, this technique can serve as a valuable alternative for the treatment of recalcitrant distal femoral nonunion with bone loss |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monroy et al., 2014 [83] | *J Knee Surg* | Prospective clinical trial | II | 29.4 | 22 | 58 | 59.1 | 6 | 4 | | Screws and Plate (19)<br>Nail (3) | Plate and screw fixation in (19)<br>IM nail in (3)<br>Autogenous iliac crest (IC) bone grafts or IC aspirates (19)<br>Cancellous chip allograft (1)<br>Additionally bone morphogenic protein (BMP) (15) | The presence of an open fracture at the initial injury may increase the likelihood of developing a distal femur nonunion, and a nonunion will likely take longer to heal |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mukhopadhaya et al., 2022 [43] | *Strategies Trauma Limb Reconstr* | Retrospective clinical trial | III | 39.5 | 31 | 43.1 | 29 | 1 | 0 | AO/OTA classification:<br>33-A2 (1)<br>33-A3 (16)<br>33-C2 (14) | ORIF with locking plate (21)<br>Only DFLP (17)<br>DFLP with PFN (1)<br>DFLP with medial plate (1)<br>LCP with cancellous screws (2)<br>DCS (1)<br>DFN (3)<br>EF (4)<br>Skeletal traction (1)<br>Thomas splint in (1) | Debridement and tissues sent for microbial culture and sensitivity (31)<br>Fixation with bone graft inserted (29)<br>DFLP (compression by lag screw or AO-Muller's compression device) (31)<br>DFLP applied over the DFN (1)<br>Additional lag screws (17) | Optimal stability, good compression at the non-union site (either by lag screws or a compression device or both), maintaining the axial alignment strictly, freshening of bone ends, using an adequate amount of cortico-cancellous bone graft, respecting the biology along with the correct choice of the implant (including the size) are essential to achieve union at the fracture site |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oh et al., 2011 [84] | *Arch Orthop Trauma Surg* | Case Report | V | 12 | 1 | 58 | 100 | 0 | 0 | AO/OTA classification: 33-A1 | MIPO with seven-hole LCP-DF plate | Taken the lag screw out, to allow motion at the fracture site, adopting the concept of "dynamization" in nailing | The screw removal employed by the authors, in this case, report can be used as a simple operation under local anesthesia before attempting other operations such as a bone graft |
| Oransky et al., 2023 [85] | *Eur J Orthop Surg Traumatol* | Retrospective case series | IV | 13.5 | 10 | 48.3 | 30 | 1 | 0 | AO/OTA classification: 33-A3 (5) 33-C1 (3) 33-C2 (1) 33-C3 (1) | Medial endosteal plate + lateral locking plate | Endosteal medial plate Lateral locking plate Autogenous bone grafting (RIA) | A medial endosteal plate is a useful augmentation for lateral plate fixation in nonunion or malunion following distal femur fractures, particularly in cases of medial bone loss, severe comminution, or poor bone quality |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Özdemir et al., 2023 [86] | *Sci Rep* | Retrospective case series | IV | 40 | 13 | 34 | 15.4 | | 0 | Recalcitrant nonunion of the distal two-thirds of the femur | Exchange RIM-nail<br>Nail dynamization<br>Iliac crest bone grafting<br>Allograft<br>Artificial growth factors (bone marrow injection, autologous platelet-rich plasma)<br>Bone stimulator | Pedicled periosteal MFC flap | A pedicled MFC flap for femur distal two-thirds has been effective in the treatment of recalcitrant femur nonunions without significant bone defects<br>There is no dependence on microvascular anastomosis<br>Besides, the operation time is relatively short, and the donor site morbidity is minimal. Surgeons may consider this flap as a useful reconstruction option for patients with previous failed femur nonunion treatments |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Palatnik and Rozbruch, 2011 [87] | *Adv Orthop* | Retrospective clinical trial | IV | 53.3 | 10 | 41.5 | 20 | | 1 | | Knee arthrodesis<br>EF<br>IMN | Ilizarov external fixator or monolateral external fixator | Ilizarov method with the use of the external fixator, as well as its latter modifications, provides surgeons with a comprehensive approach to multiple femur pathologies and by its inherent adaptability to various clinical situations can be expected to continue to play important roles in the future. It is particularly useful in the setting of bone loss, LLD, infection, large and complex deformity, and poor soft-tissue envelope |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pao and Jiang, 2005 [88] | *J Formos Med Assoc* | Case Report | V | 34 | 3 | 74.7 | 0 | 0 | 0 | | ORIF with an anatomic plate and allogenic bone grafts<br>DCS and side-plate<br>TKA | IMN<br>Bone graft | In conclusion, retrograde intramedullary nailing is a useful treatment option for nonunion of distal femoral fractures, especially after failure of plate-screw fixation. The design of total knee prostheses should consider this point and spare the intercondylar notch of the femoral component from metal coverage |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rajasekaran et al., 2020 [89] | *Int Orthop* | Retrospective clinical trial | VI | 22.1 | 24 | 71.8 | 29.7 | | 0 | | | Distal femur replacement using cemented modular endoprosthesis | By permitting immediate full weight-bearing ambulation and with most patients returning to an acceptable functional status, cemented mega prosthesis is a viable and useful single-stage management option in elderly patients with DFN |
| Reynolds et al., 2021 [90] | *J Orthop Case Rep* | Retrospective case series | VI | 25.8 | 4 | 66.75 | | 0 | 1 | | rIMN TKA | Off-label use of tantalum trabecular metal augments<br>Bone-grafting from either RIA or autologous iliac crest bone grafting | The use of tantalum metal cones for the reconstruction of distal femur non-union with segmental bone defects can be a successful technique in a complex group of patients |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rollo et al., 2019 [91] | *Med Glas (Zenica)* | Retrospective cohort study | III | 12 | 35 | 52.5 | 37.1 | | | AO/OTA classification: 33-A (16) 33-B (19) | Plate and screws (22) Plat and cerclage cable (4) Retrograde nail (6) Various treatments (wires, screws, cerclage, etc.) (3) | ORIF (29) CRIF(6) | Functional "restitutio ad integrum" is possible. The role of bio-metallic solution in the treatment of nonunions and malunions is to recreate a knee anatomy and functionality compatible with a satisfactory quality of life |
| Saridis et al., 2006 [92] | *J Bone Joint Surg Br* | Retrospective case series | IV | 42.4 | 13 | 34.6 | 23.1 | 13 | 13 | Gustilo and Anderson Type: Type 3 B Type 3 C | ORIF (5) Unilateral transarticular EF (7) Hybrid external fixation (1) | Ilizarov fixator | The use of the Ilizarov external device for definitive fixation of fractures of the distal femur is the safest and most effective method since it provides adequate fixation and stabilisation at the site of the fracture, thus increasing osseous healing and decreasing infection |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Saxena et al., 2023 [47] | *Cureus* | Prospective clinical trial | IV | 12 | 10 | 55 | 0 | | | | IM-nail (1)<br>Extramedullary implants (4) | Implant removal<br>Fixation with nail plate construct<br>Bone grafting | In our experience, this relatively novel technique of combining nail plate constructs offers encouraging outcomes in the management of non-union distal femur fractures, especially in elderly and osteopenic patients |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tis et al., 2005 [93] | *Injury* | Case Report | V | 9 | 1 | 68 | 100 | 0 | 0 | Oblique fracture of the distal femur | ORIF<br>Bone allograft<br>DCS<br>Removing DCS and plate<br>Proximally and distally locked supracondylar nail<br>Bone allograft | Nail removing<br>Square osteotomy<br>Autogenous bone grafting<br>Angled blade plate and cortical screws | Shortening has potential problems which include vascular insufficiency, knee stiffness, and knee instability, however, it is a safe and well-proven method technique of utilizing a transverse osteotomy. It is thought that it is the reduced shear force and not necessarily the method of fixation which contributed to success |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vaishya et al. 2011 [53] | *Knee Surg Sports Traumatol Arthrosc* | Retrospective case series | IV | 48 | 8 | 74 | 37.5 | 0 | 0 | | | Megaprosthesis | Megaprosthesis can be offered as a one-stage salvage procedure for difficult nonunion in distal femoral fractures associated with bone loss, osteoporosis, and secondary knee arthritis |
| Vellingiri and Nagakumar, 2021 [94] | *Cureus* | Case Report | V | 6 | 1 | 45 | 0 | | 1 | | LCP | LCP removal<br>Distal femoral nail fixation<br>Allogenic bone grafting | For infected non-union distal femur, the patient in our study had a successful clinical and functional outcome following allograft with distal femoral nailing. Loadsharing devices are significant with better practical performance |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wang and Weng, 2003 [95] | *J Bone Joint Surg Am* | Retrospective case series | IV | 34 | 13 | 60 | 84.6 | | 2 | | Blade plate or condylar buttress plate (10)<br>Antegrade locked nail (2)<br>Antegrade locked nail and a compression plate (1) | ORIF<br>Deep-frozen cortical allograft struts<br>Autogenous iliac bone grafts | Open reduction and internal fixation supplemented with allograft struts and autogenous bone graft is an effective treatment for nonunion of the distal part of the femur |
| Waseem et al., 2010 [96] | *PM R* | Case Report | V | 36 | 1 | 77 | 50 | 1 | 0 | Open comminuted left distal femur fracture<br>Closed right distal femur fracture | Left: Irrigation and debridement<br>ORIF with an LCP<br>Irrigation and debridement<br>Removal of hardware<br>Refixation with a new, longer LCP and new, nonlocking and locking screws<br>Right: ORIF with LISS plate<br>Removal of the LISS plate and fixation with an LCP<br>Removal LCP, repeat ORIF with a new LCP<br>Right iliac crest autologous bone graft | LIPUS | Rapid recovery could potentially be attributed to a dose-dependent effect given the twice-daily application of LIPUS |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wu, 2011 [97] | *Arch Orthop Trauma Surg* | Retrospective case series | IV | 30 | 13 | 36 | 15.4 | | 0 | | Plates<br>External fixation<br>Antegrade locked nails | Retrograde locked nailing:<br>Closed removal of all previous implants<br>Insertion of a retrograde dynamic locked nail, Cancellous bone grafting from the lateral tibial condyle with or without plate augmentation | Retrograde dynamic locked nailing is an excellent alternative treatment for the treatment of aseptic nonunions of femoral supracondylar after antegrade locked nailing. However, this technique may only be used when antegrade exchange locked nailing is unsuitable for use. The technique is not complex and its success rate is high |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wu, 2011 [98] | *J Trauma* | Retrospective case series | IV | 30 | 20 | 77 | 75 | 0 | 0 | | Plates | Retrograde femoral-locked nail in the dynamic mode<br>Bone cement<br>Cancellous bone graft with or without a bone graft substitute | Retrograde femoral-locked nail may concomitantly provide sufficient stability and initiate osteogenic potential, thus facilitating bone union. This technique is simple with a low complication rate and thus should be considered as a useful alternative for treating this complex lesion |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yoshida et al., 2009 [99] | *J Reconstr Microsurg* | Case Report | V | | 2 | 48 | 0 | | 0 | | IMN<br>EF and cancellous bone grafting from the iliac crest<br>LIPUS | Free vascularized bone graft harvested from the supracondylar region of the femur | The described technique is the best indication for an intractable nonunion without significant bone defects of the distal half of the femur when the standard techniques such as cancellous bone graft, dynamization, and LIPUS treatment are not practical |

**Table 1** (continued)

| Author, year | *Journal* | Design | LoE | Follow-up (months) | Patients (*n*) | Mean age (years) | Women (%) | Open fracture (*n*) | Infected (*n*) | Fracture type | Initial treatment type (*n*) | Definitive treatment type | Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Zhang et al., 2023 [100] | *J Int Med Res* | Retrospective observational study | III | 17.9 | 5 | 52 | 20 | 0 | | | LISS plate (MIPPO)<br>Variable angle plate, autogenous posterior iliac crest bone graft<br>Medial plate<br>Retrograde nail<br>RIA | IM-nailing and an LLP combined with RIA bone grafting | Combining intramedullary nailing and a lateral locking plate with the RIA bone grafting technique enhances biological properties, provides good structural support, and achieves good union and functional results in the management of resistant nonunion of the distal femur |

*OTA* Orthopaedic Trauma Association, *DFLP* distal femur locking plate, *MLP* medial locking plate, *LLP* lateral locking plate, *DSC* dynamic condylar screw, *PFN* proximal femoral nail, *LISS* less invasive stabilisation system, *LIPUS* low-intensity pulsed ultrasound, *MIPO* minimally invasive plate osteosynthesis, *EF* external fixation, *IMN* intramedullary nail, *P* plate, *rh-BMP-2* recombinant human bone morphogenetic protein-2, *LCP* locking compression plates, *LOWDFO* lateral open wedge distal femur osteotomy, *MFC* medial femoral condyle, *RIA* reamer-irrigator-aspirator

[28]. Reported time intervals ranged from 3 to 12 months [28]. A cut-off of 6 months was most commonly used to define nonunion [28]. Few studies reported a cut-off of 12 months and 9 months [28]. More recently, the US Food and Drug Administration (US FDA) proposed a cut-off of 9 months without evidence of progression to healing over the previous 3 months [29, 30]. The diagnosis of nonunion is often achieved through imaging using plain radiography [31]. However, consensus on the appropriate criteria still needs to be improved [32, 33]. The absence of bridging callus on at least three of four cortices on radiographs is a common assessment criterion, as is the movement of the fracture during radiographic stress testing, lack of bony/cortical continuity, or lack of bridging bone trabeculae [34]. Clinical criteria used to diagnose nonunion are also heterogeneous and not commonly used; among them are pain over the fracture site, pain during weight bearing and natural mobility at the fracture site [35, 36].

Several strategies are used for the management of distal femoral nonunion, with each treatment option having merits and demerits [37–40]. Dynamisation is occasionally attempted as a less invasive method to achieve union in femoral diaphyseal fractures with an axial stable fracture configuration [41, 42]. The main surgical technique used is the revision ORIF, which involves osteosynthesis with freshening of bone ends and bone grafting [43, 44]. It offers a high chance of achieving union and allows for restoring the joint alignment [43, 44]. Another minimally invasive technique involves retrograde intramedullary nailing, which is more suitable for fractures where the original surgery used plates and screws [45, 46]. Being less invasive, it reduces soft tissue disruption. It may potentially provide faster healing, but it is not suitable for all nonunion types, and there may be the possibility of malalignment if nail placement is inaccurate. A combined plate and nail fixation construct is also used, using a locking plate and an intramedullary nail for enhanced stability [47, 48]. Ilizarov external fixator is another surgical option used for treating distal femoral nonunion, and it can provide high union and low complication rates in experienced hands [49, 50]. Although autologous bone grafting is usually considered an essential part of any surgical fixation technique to promote bone growth and improve the chances of healing of nonunion, it requires an additional surgical site for graft harvesting, increasing the potential for pain and discomfort [51, 52]. It is also beneficial for complex nonunions or those with significant bone loss [52]. However, being more invasive than single procedures, there may be an increased risk of infection and hardware complications. In resistant and challenging distal femoral nonunion in older people with associated bone loss, osteoporosis, and secondary knee osteoarthritis, mega prosthesis has been successfully used as a one-stage salvage procedure [53–55].

Saxena et al. [47] reported the outcomes of 10 cases of non-union of distal femur treated by fixation with nail plate construct and bone grafting, achieving union in 10.3 months on an average duration.

The only previously systematic review on this topic was done by Ebraheim et al. [4], who assessed 19 studies and found that the most common initial treatment was ORIF with plating, and the most common definitive treatment was with fixed angle plating combined with cancellous autografting, with a union rate of 97.4% and average union time of 7.8 months.

In a retrospective study of 31 cases of distal femoral non-union, which were treated by anatomical lateral locking plates and autogenous bone grafting, stable union was achieved in all cases, with a significant improvement in the functional scores [43]. The authors concluded that optimal stability, good compression at the non-union site, maintenance of axial alignment, bone end freshening, adequate use of cortico-cancellous bone autograft, respecting the biology, and the correct choice of the implant (including the size) are essential to achieve union at the fracture site [43].

In a retrospective study of 18 cases of atrophic distal femoral non-union that were managed using a combination of J-shaped bone graft and double plating union was achieved in all cases at an average of $22.1 \pm 5.5$ months (range 14–34 months) postoperatively [56]. The average healing time was $6.72 \pm 2.80$ months [56].

A recently published bibliometric study (1990–2023) found a growing interest in fracture non-union globally through published studies [57].

Distal femoral fractures are complex injuries, and even with advancements in treatment, non-union remains a potential complication. While there has been progress in understanding and treating this condition, there are still gaps in the current research. Studies have not yet established a clear consensus on the most optimal surgical technique for nonunions, and guidelines for managing nonunion, especially of the distal femur, are missing. More research is needed on long-term patient outcomes after treatment for non-union. This can help assess the effectiveness of different approaches and identify areas for improvement. More research is needed to better understand the influence of patient characteristics, such as age, comorbidities, and bone quality, on the risk of developing non-union and treatment success. Further investigations into these areas can lead to more standardised protocols, improved success rates, and improved outcomes. Strategies to improve the outcome of the surgical management of nonunion treatment are evolving.

Logistic regression predictive models can help develop and identify patients at high risk of non-union before surgery. This would allow for early intervention and potentially

a reduction in non-union rates [14]. Specific growth factors, like bone morphogenetic proteins (BMP), are used locally at the fracture site to stimulate bone formation, enhance healing, and potentially reduce the need for extensive grafting procedures [58]. However, its use is still limited, as it is a relatively new approach with ongoing research and high cost compared to traditional methods [59, 60]. Genetic influence has been proposed, especially polymorphisms in the genes *ANXA3*, *BMP2*, *CALY*, *CYR61*, *FGFR1*, *IL1β*, *NOG*, *NOS2*, *PDGF gene*, and *TACR1* are susceptible to nonunion [61, 62]. Hence, gene therapy may help stimulate bone growth and improve healing rates in non-unions [63]. Refinement in minimally invasive surgical (MIS) techniques for treating non-unions could lead to faster recovery times and less surgical burden on patients [64, 65]. In this context, there is also interest in robotic-assisted surgery (RAS), which might improve precision and accuracy during revision surgery for non-unions [66, 67]. Developing bioactive implants that promote bone healing and enhance the fusion rate at the fracture site could be crucial [68]. Using biodegradable implants would also eliminate the need for a second surgery to remove hardware. Moreover, advanced imaging techniques like Magnetic Resonance Imaging (MRI) may better assess bone healing progress in patients [24, 69]. However, the presence of metallic implants may generate artefacts. Developing biosensors to monitor the bone healing process in real-time may thus allow for adjustments to treatment plans as needed [70, 71]. Focusing on these areas, researchers are developing more effective strategies for distal femoral nonunion, leading to improved patient outcomes and a faster return to function.

## Conclusion

This systematic review of distal femoral nonunion based on 35 studies and 832 cases revealed that with appropriate surgical treatment 84.5% of patients reached complete union without major complications, and 3.8% (32 of 832) reached complete union with major complications at a mean of $21.7 \pm 20.9$ months. But, 8.7% (72 of 832) patients showed signs of persistent non-union.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s43465-024-01205-4.

**Author Contributions** FM: literature search, statistical analysis, study selection and data extraction, risk of bias assessment, drafting (original and revision); LS: literature search, study selection and data extraction, risk of bias assessment; FS: editing; AV: editing; JSB: literature search, manuscript preparation, and editing, RV: conception and design, drafting (original and revision). All authors have agreed to the final version to be published and agree to be accountable for all aspects of the work.

**Funding** The authors received no financial support for the research, authorship, and/or publication of this article.

**Availability of Data and Materials** The datasets generated during and/or analysed during the current study are available throughout the manuscript.

## Declarations

**Conflict of Interest** The authors declare that they have any competing interests in this article.

**Ethical Approval** This study complies with ethical standards.

**Informed Consent** For this type of study informed consent is not required.

**Consent to Participate** Not applicable.

**Consent to Publish** Not applicable.

**Registration and Protocol** The present review was not registered.

## References

1. Coon, M. S., & Best, B. J. (2024). Distal femur fractures. In *StatPearls*. Treasure Island (FL) Ineligible Companies. Disclosure: Ben Best declares no relevant financial relationships with Ineligible Companies.
2. Khan, A. M., Tang, Q. O., & Spicer, D. (2017). The epidemiology of adult distal femoral shaft fractures in a Central London Major Trauma Centre over five years. *The Open Orthopaedics Journal, 11*, 1277–1291. https://doi.org/10.2174/1874325001711011277
3. Von Rehlingen-Prinz, F., Eggeling, L., Dehoust, J., Huppke, C., Strahl, A., Neumann-Langen, M. V., Glaab, R., Frosch, K. H., & Krause, M. (2023). Current standard of care for distal femur fractures in Germany and Switzerland. *Injury, 54*(10), 110936. https://doi.org/10.1016/j.injury.2023.110936
4. Ebraheim, N. A., Martin, A., Sochacki, K. R., & Liu, J. (2013). Nonunion of distal femoral fractures: A systematic review. *Orthopaedic Surgery, 5*(1), 46–50. https://doi.org/10.1111/os.12017
5. Koso, R. E., Terhoeve, C., Steen, R. G., & Zura, R. (2018). Healing, nonunion, and re-operation after internal fixation of diaphyseal and distal femoral fractures: A systematic review and meta-analysis. *International Orthopaedics, 42*(11), 2675–2683. https://doi.org/10.1007/s00264-018-3864-4
6. Yoon, B. H., Park, I. K., Kim, Y., Oh, H. K., Choo, S. K., & Sung, Y. B. (2021). Incidence of nonunion after surgery of distal femoral fractures using contemporary fixation device: A meta-analysis. *Archives of Orthopaedic and Trauma Surgery, 141*(2), 225–233. https://doi.org/10.1007/s00402-020-03463-x
7. Tay, W. H., de Steiger, R., Richardson, M., Gruen, R., & Balogh, Z. J. (2014). Health outcomes of delayed union and nonunion of femoral and tibial shaft fractures. *Injury, 45*(10), 1653–1658. https://doi.org/10.1016/j.injury.2014.06.025
8. Brinker, M. R., Trivedi, A., & O'Connor, D. P. (2017). Debilitating effects of femoral nonunion on health-related quality of life. *Journal of Orthopaedic Trauma, 31*(2), e37–e42. https://doi.org/10.1097/bot.0000000000000736

9. Kim, J. W., Byun, S. E., Oh, H. K., & Kim, J. J. (2015). Indolent infection in nonunion of the distal femur. *European Journal of Orthopaedic Surgery & Traumatology, 25*(3), 549–553. https://doi.org/10.1007/s00590-014-1531-z
10. Cone, R., Roszman, A., Conway, Y., Cichos, K., McGwin, G., & Spitler, C. A. (2023). Risk factors for nonunion of distal femur fractures. *Journal of Orthopaedic Trauma, 37*(4), 175–180. https://doi.org/10.1097/BOT.0000000000002553
11. Landes, E. K., Konda, S. R., Leucht, P., Ganta, A., & Egol, K. A. (2023). Fixed-angle plate fixation and autogenous iliac crest graft for repair of distal metaphyseal femoral nonunion. *European Journal of Orthopaedic Surgery & Traumatology, 33*(5), 1835–1839. https://doi.org/10.1007/s00590-022-03366-0
12. Peng, Y., Ji, X., Zhang, L., & Tang, P. (2016). Double locking plate fixation for femoral shaft nonunion. *European Journal of Orthopaedic Surgery & Traumatology, 26*(5), 501–507. https://doi.org/10.1007/s00590-016-1765-z
13. Wang, M. T., An, V. V. G., & Sivakumar, B. S. (2019). Nonunion in lateral locked plating for distal femoral fractures: A systematic review. *Injury, 50*(11), 1790–1794. https://doi.org/10.1016/j.injury.2019.07.012
14. Sainio, H., Ramo, L., Reito, A., Silvasti-Lundell, M., & Lindahl, J. (2023). Prediction of fracture nonunion leading to secondary surgery in patients with distal femur fractures. *Bone and Joint Open, 4*(8), 584–593. https://doi.org/10.1302/2633-1462.48.BJO-2023-0077.R1
15. Christiano, A. V., Pean, C. A., Konda, S. R., & Egol, K. A. (2016). Predictors of patient reported pain after lower extremity nonunion surgery: The nicotine effect. *Iowa Orthopaedic Journal, 36*, 53–58.
16. Quan, K., Xu, Q., Zhu, M., Liu, X., & Dai, M. (2021). Analysis of risk factors for non-union after surgery for limb fractures: A case-control study of 669 subjects. *Frontiers in Surgery, 8*, 754150. https://doi.org/10.3389/fsurg.2021.754150
17. Graf, R. M., Shaw, J. T., Simske, N. M., Siy, P. N., Siy, A. B., Kliethermes, S. A., & Whiting, P. S. (2023). Distal femur nonunion: Risk factors and validation of RUST scores. *OTA International: The Open Access Journal of Orthopaedic Trauma, 6*, e234. https://doi.org/10.1097/oi9.0000000000000234
18. Rodriguez, E. K., Boulton, C., Weaver, M. J., Herder, L. M., Morgan, J. H., Chacko, A. T., Appleton, P. T., Zurakowski, D., & Vrahas, M. S. (2014). Predictive factors of distal femoral fracture nonunion after lateral locked plating: A retrospective multicenter case-control study of 283 fractures. *Injury, 45*(3), 554–559. https://doi.org/10.1016/j.injury.2013.10.042
19. Karam, J., Campbell, P., David, M., & Hunter, M. (2019). Comparison of outcomes and analysis of risk factors for nonunion in locked plating of closed periprosthetic and non-periprosthetic distal femoral fractures in a retrospective cohort study. *J Orthop Surg Res., 14*(1), 150. https://doi.org/10.1186/s13018-019-1204-z.
20. Howick, J. C. I., Glasziou, P., Greenhalgh, T., Heneghan, C., Liberati, A., Moschetti, I., Phillips, B., Thornton, H., Goddard, O., & Hodgkinson, M. (2011). *The 2011 Oxford CEBM levels of evidence*. Oxford Centre for Evidence-Based Medicine.
21. Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hrobjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71
22. Cumpston, M., Li, T., Page, M. J., Chandler, J., Welch, V. A., Higgins, J. P., & Thomas, J. (2019). Updated guidance for trusted systematic reviews: A new edition of the Cochrane Handbook for Systematic Reviews of Interventions. *Cochrane Database of Systematic Reviews, 10*, ED000142. https://doi.org/10.1002/14651858.ED000142
23. Sterne, J. A., Hernan, M. A., Reeves, B. C., Savovic, J., Berkman, N. D., Viswanathan, M., Henry, D., Altman, D. G., Ansari, M. T., Boutron, I., Carpenter, J. R., Chan, A. W., Churchill, R., Deeks, J. J., Hrobjartsson, A., Kirkham, J., Juni, P., Loke, Y. K., Pigott, T. D., … Higgins, J. P. (2016). ROBINS-I: A tool for assessing risk of bias in non-randomised studies of interventions. *BMJ, 355*, i4919. https://doi.org/10.1136/bmj.i4919
24. Nicholson, J. A., Makaram, N., Simpson, A., & Keating, J. F. (2021). Fracture nonunion in long bones: A literature review of risk factors and surgical management. *Injury, 52*(Suppl 2), S3–S11. https://doi.org/10.1016/j.injury.2020.11.029
25. Hou, G., Zhou, F., Tian, Y., Ji, H., Zhang, Z., Guo, Y., Lv, Y., Yang, Z., & Zhang, Y. (2020). Analysis of risk factors for revision in distal femoral fractures treated with lateral locking plate: A retrospective study in Chinese patients. *Journal of Orthopaedic Surgery and Research, 15*(1), 318. https://doi.org/10.1186/s13018-020-01850-z
26. Tornetta, P., III., Della Rocca, G. J., Morshed, S., Jones, C., Heels-Ansdell, D., Sprague, S., Petrisor, B., Jeray, K. J., Del Fabbro, G., Bzovsky, S., & Bhandari, M. (2020). Risk factors associated with infection in open fractures of the upper and lower extremities. *J Am Acad Orthop Surg Glob Res Rev, 4*(12), e20.00188. https://doi.org/10.5435/JAAOSGlobal-D-20-00188
27. Hellwinkel, J. E., Working, Z. M., Certain, L., García, A. J., Wenke, J. C., & Bahney, C. S. (2022). The intersection of fracture healing and infection: Orthopaedics research society workshop 2021. *Journal of Orthopaedic Research, 40*(3), 541–552. https://doi.org/10.1002/jor.25261
28. Wittauer, M., Burch, M. A., McNally, M., Vandendriessche, T., Clauss, M., Della Rocca, G. J., Giannoudis, P. V., Metsemakers, W. J., & Morgenstern, M. (2021). Definition of long-bone nonunion: a scoping review of prospective clinical trials to evaluate current practice. *Injury, 52*(11), 3200–3205. https://doi.org/10.1016/j.injury.2021.09.008
29. Cunningham, B. P., Brazina, S., Morshed, S., & Miclau, T., 3rd. (2017). Fracture healing: a review of clinical, imaging and laboratory diagnostic options. *Injury, 48*(Suppl 1), S69–S75. https://doi.org/10.1016/j.injury.2017.04.020
30. Roberts, T. T., & Rosenbaum, A. J. (2012). Bone grafts, bone substitutes and orthobiologics: The bridge between basic science and clinical advancements in fracture healing. *Organogenesis, 8*(4), 114–124. https://doi.org/10.4161/org.23306
31. Morshed, S. (2014). Current options for determining fracture union. *Advances in Medicine, 2014*, 708574. https://doi.org/10.1155/2014/708574
32. Corrales, L. A., Morshed, S., Bhandari, M., & Miclau, T., 3rd. (2008). Variability in the assessment of fracture-healing in orthopaedic trauma studies. *Journal of Bone and Joint Surgery. American Volume, 90*(9), 1862–1868. https://doi.org/10.2106/jbjs.G.01580
33. Bhandari, M., Guyatt, G. H., Swiontkowski, M. F., Tornetta, P., 3rd., Sprague, S., & Schemitsch, E. H. (2002). A lack of consensus in the assessment of fracture healing among orthopaedic surgeons. *Journal of Orthopaedic Trauma, 16*(8), 562–566. https://doi.org/10.1097/00005131-200209000-00004
34. Knox, A. M., McGuire, A. C., Natoli, R. M., Kacena, M. A., & Collier, C. D. (2021). Methodology, selection, and integration of fracture healing assessments in mice. *Journal of Orthopaedic Research, 39*(11), 2295–2309. https://doi.org/10.1002/jor.25172
35. Thomas, J. D., & Kehoe, J. L. (2024). Bone nonunion. In *StatPearls*. StatPearls Publishing Copyright © 2024, StatPearls Publishing LLC.
36. Schmal, H., Brix, M., Bue, M., Ekman, A., Ferreira, N., Gottlieb, H., Kold, S., Taylor, A., Toft Tengberg, P., & Ban, I. (2020).

Nonunion—Consensus from the 4th annual meeting of the Danish Orthopaedic Trauma Society. *EFORT Open Reviews, 5*(1), 46–57. https://doi.org/10.1302/2058-5241.5.190037
37. Claireaux, H. A., Searle, H. K., Parsons, N. R., & Griffin, X. L. (2022). Interventions for treating fractures of the distal femur in adults. *Cochrane Database Systematic Review, 10*(10), CD010606. https://doi.org/10.1002/14651858.CD010606.pub3
38. Amorosa, L. F., Jayaram, P. R., Wellman, D. S., Lorich, D. G., & Helfet, D. L. (2014). The use of the 95-degree-angled blade plate in femoral nonunion surgery. *European Journal of Orthopaedic Surgery & Traumatology, 24*(6), 953–960. https://doi.org/10.1007/s00590-013-1267-1
39. Özdemir, A., Odabaşı, E., Eravsar, E., Safalı, S., & Acar, M. A. (2023). Treatment of recalcitrant femur nonunion with pedicled corticoperiosteal medial femoral condyle flap. *Science and Reports, 13*(1), 20326. https://doi.org/10.1038/s41598-023-47432-x
40. Gangavalli, A. K., & Nwachuku, C. O. (2016). Management of distal femur fractures in adults: An overview of options. *Orthopedic Clinics of North America, 47*(1), 85–96. https://doi.org/10.1016/j.ocl.2015.08.011
41. Hu, M., Zeng, W., Zhang, J., Feng, Y., Ma, L., Huang, F., & Cai, Q. (2023). Fixators dynamization for delayed union and non-union of femur and tibial fractures: A review of techniques, timing and influence factors. *Journal of Orthopaedic Surgery and Research, 18*(1), 577. https://doi.org/10.1186/s13018-023-04054-3
42. Stolberg-Stolberg, J., Fuchs, T., Lodde, M. F., Rosslenbroich, S., Garcia, P., Raschke, M., & Everding, J. (2022). Addition of shock wave therapy to nail dynamization increases the chance of long-bone non-union healing. *Journal of Orthopaedics and Traumatology, 23*(1), 4. https://doi.org/10.1186/s10195-021-00620-9
43. Mukhopadhaya, J., Ranjan, R., Sinha, A. K., & Bhadani, J. S. (2022). The management of aseptic non-unions of distal femur fractures with anatomical lateral locking plates. *Strategies in Trauma and Limb Reconstruction, 17*(3), 137–143. https://doi.org/10.5005/jp-journals-10080-1564
44. van Trikt, C. H., Donders, J. C. E., Klinger, C. E., Wellman, D. S., Helfet, D. L., & Kloen, P. (2022). Operative treatment of nonunions in the elderly: Clinical and radiographic outcomes in patients at minimum 75 years of age. *BMC Geriatrics, 22*(1), 985. https://doi.org/10.1186/s12877-022-03670-8
45. Koval, K. J., Seligson, D., Rosen, H., & Fee, K. (1995). Distal femoral nonunion: Treatment with a retrograde inserted locked intramedullary nail. *Journal of Orthopaedic Trauma, 9*(4), 285–291. https://doi.org/10.1097/00005131-199509040-00003
46. Wu, C. C. (2016). Retrograde dynamic locked intramedullary nailing for aseptic supracondylar femoral nonunion after dynamic condylar screw treatment. *European Journal of Orthopaedic Surgery & Traumatology, 26*(6), 625–631. https://doi.org/10.1007/s00590-016-1800-0
47. Saxena, V., Akshay, V., Panwar, A., & Kumar, S. (2023). Management of non-union distal femur fractures with augmentation nail plate construct. *Cureus, 15*(4), e37173. https://doi.org/10.7759/cureus.37173
48. Liporace, F. A., Tang, A., Jankowski, J. M., & Yoon, R. S. (2022). Distal femur: Nail plate combination and the linked construct. *OTA International, 5*(3), e172. https://doi.org/10.1097/oi9.0000000000000172
49. Cavusoglu, A. T., Ozsoy, M. H., Dincel, V. E., Sakaogullari, A., Basarir, K., & Ugurlu, M. (2009). The use of a low-profile Ilizarov external fixator in the treatment of complex fractures and non-unions of the distal femur. *Acta Orthopaedica Belgica, 75*(2), 209–218.
50. Rohilla, R., Sharma, P. K., Dua, M., Singh, R., Beniwal, D., & Khokhar, A. (2023). Outcome of monolateral rail fixator in infected nonunion of femur diaphysis developing after intramedullary fixation. *European Journal of Orthopaedic Surgery & Traumatology, 33*(4), 1223–1230. https://doi.org/10.1007/s00590-022-03275-2
51. Murphy, N. J., Graan, D., Briggs, G. D., & Balogh, Z. J. (2023). Acute minimally invasive bone grafting of long bone fractures to reduce the incidence of fracture non-union. *Medical Hypotheses, 178*, 111131.
52. Flierl, M. A., Smith, W. R., Mauffrey, C., Irgit, K., Williams, A. E., Ross, E., Peacher, G., Hak, D. J., & Stahel, P. F. (2013). Outcomes and complication rates of different bone grafting modalities in long bone fracture nonunions: A retrospective cohort study in 182 patients. *Journal of Orthopaedic Surgery and Research, 8*, 33. https://doi.org/10.1186/1749-799X-8-33
53. Vaishya, R., Singh, A. P., Hasija, R., & Singh, A. P. (2011). Treatment of resistant nonunion of supracondylar fractures femur by megaprosthesis. *Knee Surgery, Sports Traumatology, Arthroscopy, 19*(7), 1137–1140. https://doi.org/10.1007/s00167-011-1416-1
54. Rajasekaran, R. B., Palanisami, D. R., Natesan, R., Jayaramaraju, D., & Rajasekaran, S. (2020). Reply to "Megaprosthesis in distal femur nonunions in elderly patients-experience from twenty-four cases: A letter to editor." *International Orthopaedics, 44*(10), 2191–2192. https://doi.org/10.1007/s00264-020-04586-x
55. Vaishya, R., Thapa, S. S., & Vaish, A. (2020). Non-neoplastic indications and outcomes of the proximal and distal femur megaprosthesis: A critical review. *Knee Surgery and Related Research, 32*(1), 18. https://doi.org/10.1186/s43019-020-00034-7
56. Lu, J., Guo, S. C., Wang, Q. Y., Sheng, J. G., & Tao, S. C. (2020). J-bone graft with double locking plate: A symphony of mechanics and biology for atrophic distal femoral non-union with bone defect. *Journal of Orthopaedic Surgery and Research, 15*(1), 144. https://doi.org/10.1186/s13018-020-01636-3
57. Vaishya, R., Gupta, B. M., Mamdapur, G. M. N., Vaish, A., Bhadani, J. S., & Mukhopadhaya, J. (2024). Highly-cited papers on fracture non-union—A bibliometric analysis of the global literature (1990–2023). *Indian Journal of Orthopaedics,* 1–12.
58. Georgeanu, V. A., Gingu, O., Antoniac, I. V., & Manolea, H. O. (2023). Current options and future perspectives on bone graft and biomaterials substitutes for bone repair, from clinical needs to advanced biomaterials research. *Applied Sciences, 13*(14), 8471.
59. Polmear, M. M., Anderson, A. B., Lanier, P. J., Orr, J. D., Nesti, L. J., & Dunn, J. C. (2021). Bone morphogenetic protein in scaphoid nonunion: A systematic review. *Journal of Wrist Surgery, 10*(3), 184–189. https://doi.org/10.1055/s-0040-1722332
60. Lampert, F. M., Momeni, A., Filev, F., Torio-Padron, N., Finkenzeller, G., Stark, G. B., Steiner, D., & Koulaxouzidis, G. (2015). Utilization of a genetically modified muscle flap for local BMP-2 production and its effects on bone healing: A histomorphometric and radiological study in a rat model. *Journal of Orthopaedic Surgery and Research, 10*, 55. https://doi.org/10.1186/s13018-015-0196-6
61. Sadat-Ali, M., Al-Omar, H. K., AlTabash, K. W., AlOmran, A. K., AlDakheel, D. A., & AlSayed, H. N. (2023). Genetic influence of fracture nonunion (FNU): A systematic review. *Pharmacogenomics and Personalized Medicine, 16*, 569–575. https://doi.org/10.2147/PGPM.S407308
62. Salichos, L., Thayavally, R., Kloen, P., & Hadjiargyrou, M. (2024). Human nonunion tissues display differential gene expression in comparison to physiological fracture callus. *Bone, 183*, 117091. https://doi.org/10.1016/j.bone.2024.117091
63. De la Vega, R. E., Atasoy-Zeybek, A., Panos, J. A., Vang, M., Evans, C. H., & Balmayor, E. R. (2021). Gene therapy for bone healing: Lessons learned and new approaches. *Translational Research, 236*, 1–16. https://doi.org/10.1016/j.trsl.2021.04.009

64. Pietu, G., & Ehlinger, M. (2017). Minimally invasive internal fixation of distal femur fractures. *Orthopaedics & Traumatology, Surgery & Research, 103*(1S), S161–S169. https://doi.org/10.1016/j.otsr.2016.06.025
65. Beeres, F. J. P., Emmink, B. L., Lanter, K., Link, B. C., & Babst, R. (2020). Minimally invasive double-plating osteosynthesis of the distal femur. *Operative Orthopädie und Traumatologie, 32*(6), 545–558. https://doi.org/10.1007/s00064-020-00664-w
66. Schuijt, H. J., Hundersmarck, D., Smeeing, D. P. J., van der Velde, D., & Weaver, M. J. (2021). Robot-assisted fracture fixation in orthopaedic trauma surgery: A systematic review. *OTA International, 4*(4), e153. https://doi.org/10.1097/OI9.0000000000000153
67. Yi, Z., Lim, R. Q. R., Chen, W., Zhu, J., Chen, S., & Liu, B. (2024). Arthroscopic bone grafting and robot-assisted fixation for scaphoid nonunion. *Orthopaedic Surgery, 16*(1), 254–262. https://doi.org/10.1111/os.13930
68. Szwed-Georgiou, A., Plocinski, P., Kupikowska-Stobba, B., Urbaniak, M. M., Rusek-Wala, P., Szustakiewicz, K., Piszko, P., Krupa, A., Biernat, M., Gazinska, M., Kasprzak, M., Nawrotek, K., Mira, N. P., & Rudnicka, K. (2023). Bioactive materials for bone regeneration: Biomolecules and delivery systems. *ACS Biomaterials Science & Engineering, 9*(9), 5222–5254. https://doi.org/10.1021/acsbiomaterials.3c00609
69. Warwick, R., Willatt, J. M., Singhal, B., Borremans, J., & Meagher, T. (2009). Comparison of computed tomographic and magnetic resonance imaging in fracture healing after spinal injury. *Spinal Cord, 47*(12), 874–877. https://doi.org/10.1038/sc.2009.59
70. Rani, S., Bandyopadhyay-Ghosh, S., Ghosh, S. B., & Liu, G. (2020). Advances in sensing technologies for monitoring of bone health. *Biosensors (Basel)*. https://doi.org/10.3390/bios10040042
71. Windolf, M., Varjas, V., Gehweiler, D., Schwyn, R., Arens, D., Constant, C., Zeiter, S., Richards, R. G., & Ernst, M. (2022). Continuous implant load monitoring to assess bone healing status-evidence from animal testing. *Medicina (Kaunas, Lithuania)*. https://doi.org/10.3390/medicina58070858
72. Ali, F., & Saleh, M. (2002). Treatment of distal femoral nonunions by external fixation with simultaneous length and alignment correction. *Injury*, *33*(2), 127–134. https://doi.org/10.1016/s0020-1383(01)00032-8.
73. Alt, V., Meyer, C., Litzlbauer, H. D., & Schnettler, R. (2007). Treatment of a double nonunion of the femur by rhBMP-2. *Journal of Orthopaedic Trauma, 21*(10), 734–737. https://doi.org/10.1097/BOT.0b013e3181589700
74. Bellabarba, C., Ricci, W. M., & Bolhofner, B. R. (2002). Indirect reduction and plating of distal femoral nonunions. *Journal of Orthopaedic Trauma, 16*(5), 287–296. https://doi.org/10.1097/00005131-200205000-00001
75. Chen, X., Li, J. J., Kong, Z., Yang, D. X., & Yuan, X. N. (2011). Autologous grafts of double-strut fibular cortical bone plate to treat the fractures and defects of distal femur: A case report and review of literature. *Chinese Journal of Traumatology, 14*(4), 241–246.
76. Davila, J., Malkani, A., & Paiso, J. M. (2001). Supracondylar distal femoral nonunions treated with a megaprosthesis in elderly patients: A report of two cases. *Journal of Orthopaedic Trauma, 15*(8), 574–578. https://doi.org/10.1097/00005131-200111000-00009
77. Ebraheim, N. A., Buchanan, G. S., Liu, X., Cooper, M. E., Peters, N., Hessey, J. A., & Liu, J. (2016). Treatment of distal femur nonunion following initial fixation with a lateral locking plate. *Orthopaedic Surgery, 8*(3), 323–330. https://doi.org/10.1111/os.12257
78. Gardner, M. J., Toro-Arbelaez, J. B., Harrison, M., Hierholzer, C., Lorich, D. G., & Helfet, D. L. (2008). Open reduction and internal fixation of distal femoral nonunions: Long-term functional outcomes following a treatment protocol. *Journal of Trauma, 64*(2), 434–438. https://doi.org/10.1097/01.ta.0000245974.46709.2e
79. Graves, M. L., Ryan, J. E., & Mast, J. W. (2005). Supracondylar femur nonunion associated with previous vascular repair: Importance of vascular exam in preoperative planning of nonunion repair. *Journal of Orthopaedic Trauma, 19*(8), 574–577. https://doi.org/10.1097/01.bot.0000151818.63175.b9
80. Hailer, Y. D., & Hoffmann, R. (2006). Management of a nonunion of the distal femur in osteoporotic bone with the internal fixation system LISS (less invasive stabilization system). *Archives of Orthopaedic and Trauma Surgery, 126*(5), 350–353. https://doi.org/10.1007/s00402-006-0102-0
81. Holzman, M. A., Hanus, B. D., Munz, J. W., O'Connor, D. P., & Brinker, M. R. (2016). Addition of a medial locking plate to an in situ lateral locking plate results in healing of distal femoral nonunions. *Clinical Orthopaedics and Related Research, 474*(6), 1498–1505. https://doi.org/10.1007/s11999-016-4709-3
82. Ma, C. H., Chiu, Y. C., Tu, Y. K., Yen, C. Y., & Wu, C. H. (2017). Three-stage treatment protocol for recalcitrant distal femoral nonunion. *Archives of Orthopaedic and Trauma Surgery, 137*(4), 489–498. https://doi.org/10.1007/s00402-017-2634-x
83. Monroy, A., Urruela, A., Singh, P., Tornetta, P., 3rd., & Egol, K. A. (2014). Distal femur nonunion patients can expect good outcomes. *The Journal of Knee Surgery, 27*(1), 83–87. https://doi.org/10.1055/s-0033-1349402
84. Oh, J. K., Hwang, J. H., Lee, S. J., & Kim, J. I. (2011). Dynamization of locked plating on distal femur fracture. *Archives of Orthopaedic and Trauma Surgery, 131*(4), 535–539. https://doi.org/10.1007/s00402-010-1202-4
85. Oransky, M., Galante, C., Cattaneo, S., Milano, G., Motta, M., Biancardi, E., Grava, G., Johnson, E. E., & Casiraghi, A. (2023). Endosteal plating for the treatment of malunions and nonunions of distal femur fractures. *European Journal of Orthopaedic Surgery & Traumatology, 33*(6), 2243–2251. https://doi.org/10.1007/s00590-022-03458-x
86. Ozdemir, A., Odabasi, E., Eravsar, E., Safali, S., & Acar, M. A. (2023). Treatment of recalcitrant femur nonunion with pedicled corticoperiosteal medial femoral condyle flap. *Science and Reports, 13*(1), 20326. https://doi.org/10.1038/s41598-023-47432-x
87. Palatnik, Y., & Rozbruch, S. R. (2011). Femoral reconstruction using external fixation. *Advances in Orthopedics, 2011*, 967186. https://doi.org/10.4061/2011/967186
88. Pao, J. L., & Jiang, C. C. (2005). Retrograde intramedullary nailing for nonunions of supracondylar femur fracture of osteoporotic bones. *Journal of the Formosan Medical Association, 104*(1), 54–59.
89. Rajasekaran, R. B., Palanisami, D. R., Natesan, R., Jayaramaraju, D., & Rajasekaran, S. (2020). Megaprosthesis in distal femur nonunions in elderly patients-experience from twenty four cases. *International Orthopaedics, 44*(4), 677–684. https://doi.org/10.1007/s00264-019-04383-1
90. Reynolds, A. W., Melvin, P. R., Yakish, E. J., Sotereanos, N., Altman, G. T., & Sewecke, J. J. (2021). Use of tantalum trabecular metal cones for management of nonunion of the distal femur with segmental bone defects: Technique and case series. *Journal of Orthopaedic Case Reports, 11*(7), 19–23. https://doi.org/10.13107/jocr.2021.v11.i07.2298
91. Rollo, G., Pichierri, P., Grubor, P., Marsilio, A., Bisaccia, M., Grubor, M., Pace, V., Lanzetti, R. M., Giaracuni, M., Filipponi, M., & Meccariello, L. (2019). The challenge of nonunion and

malunion in distal femur surgical revision. *Medicinski Glasnik (Zenica)*. https://doi.org/10.17392/1016-19
92. Saridis, A., Panagiotopoulos, E., Tyllianakis, M., Matzaroglou, C., Vandoros, N., & Lambiris, E. (2006). The use of the Ilizarov method as a salvage procedure in infected nonunion of the distal femur with bone loss. *Journal of Bone and Joint Surgery. British Volume, 88*(2), 232–237. https://doi.org/10.1302/0301-620X.88B2.16976
93. Tis, J. E., Reiter, F. O., & Saleh, M. (2005). Treatment of a supracondylar femoral nonunion in a patient with osteoporosis by square osteotomy and acute shortening. *Injury, 36*(3), 454–457. https://doi.org/10.1016/j.injury.2004.11.009
94. Vellingiri, K., & Nagakumar, J. S. (2021). Infected non-union of the distal femur. *Cureus, 13*(1), e12613. https://doi.org/10.7759/cureus.12613
95. Wang, J. W., & Weng, L. H. (2003). Treatment of distal femoral nonunion with internal fixation, cortical allograft struts, and autogenous bone-grafting. *Journal of Bone and Joint Surgery. American Volume, 85*(3), 436–440. https://doi.org/10.2106/00004623-200303000-00006
96. Waseem, Z., Ford, M., Syed, K., & Flannery, J. (2010). Chronic nonunion in a patient with bilateral supracondylar distal femur fractures treated successfully with twice daily low-intensity pulsed ultrasound. *PM & R, 2*(2), 159–161. https://doi.org/10.1016/j.pmrj.2009.11.008
97. Wu, C. C. (2011). Retrograde dynamic locked nailing for aseptic nonunion of femoral supracondyle after antegrade locked nailing. *Archives of Orthopaedic and Trauma Surgery, 131*(4), 513–517. https://doi.org/10.1007/s00402-010-1183-3
98. Wu, C. C. (2011). Modified retrograde-locked nailing for aseptic femoral supracondylar nonunion with severe osteoporosis in elderly patients. *Journal of Trauma, 71*(2), E26–E30. https://doi.org/10.1097/TA.0b013e3181f64ab1
99. Yoshida, A., Yajima, H., Murata, K., Maegawa, N., Kobata, Y., Kawamura, K., & Takakura, Y. (2009). Pedicled vascularized bone graft from the medial supracondylar region of the femur for treatment of femur nonunion. *Journal of Reconstructive Microsurgery, 25*(3), 165–170. https://doi.org/10.1055/s-0028-1103503
100. Zhang, J. H., Liu, H., Cai, T. Y., Lin, Y. Z., & Wu, J. (2023). Resistant distal femoral nonunion treated with combined nail/plate construct and reamer-irrigator-aspirator technique. *Journal of International Medical Research, 51*(7), 3000605231187945. https://doi.org/10.1177/03000605231187945