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Comparative Study of Locking Plate Versus Intramedullary Nailing in Distal Femur Fractures: A Systematic Review and Meta-analysis

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ABSTRACT

Background Distal femur fractures are complex injuries frequently associated with metaphyseal comminution, intra-articular extension, osteoporosis, soft-tissue damage, impaired mobility, and a substantial risk of postoperative complications. Locking plate fixation and retrograde intramedullary nailing are the principal internal fixation techniques, but the relative superiority of either method remains uncertain.

Objective To compare the radiological, clinical, functional, and perioperative outcomes of locking plate fixation and retrograde intramedullary nailing in adult patients with distal femur fractures.

Methods A systematic review and meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. MEDLINE/PubMed, Embase, Scopus, CINAHL, and the Cochrane Library were searched from database inception to February 25, 2022. Randomized and nonrandomized comparative studies evaluating retrograde intramedullary nailing and locking plate fixation for acute distal femur fractures in adults were eligible. The primary outcomes included fracture-union time, nonunion, delayed union, malunion, infection, implant-related complications, overall complications, and reoperation. Secondary outcomes included operative duration, intraoperative blood loss, postoperative knee range of motion, and functional outcome. Risk ratios or odds ratios were used for dichotomous outcomes, while mean differences were used for continuous outcomes. Statistical heterogeneity was evaluated using the I^2 statistic.

Results The database search identified 1,945 records. After removal of duplicate and clearly irrelevant records, 258 articles underwent further assessment. Twenty-eight full-text articles were reviewed, of which 16 comparative studies involving 936 patients fulfilled the eligibility criteria. The included evidence consisted of randomized, prospective comparative, and retrospective comparative studies. Retrograde intramedullary nailing was associated with significantly lower rates of nonunion and postoperative infection than locking plate fixation. Locking plate fixation was associated with a significantly greater postoperative knee range of motion. No significant differences were observed between the techniques for mean time to fracture union, overall complications, reoperation, or operative duration. Evidence concerning blood loss, implant failure, malunion, knee pain, and functional scores was heterogeneous and did not consistently favour either implant.

Conclusion Both locking plate fixation and retrograde intramedullary nailing are effective treatments for distal femur fractures. Retrograde intramedullary nailing may offer advantages in reducing nonunion and infection, whereas locking plate fixation may provide a modest advantage in postoperative knee motion and offers greater flexibility for very distal and complex intra-articular fractures. Implant selection should be individualized according to fracture morphology, distal bone stock, articular involvement, bone quality, soft-tissue condition, prosthesis compatibility, and surgeon expertise.

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Keywords*: distal femur fracture; locking compression plate; lateral locking plate; retrograde intramedullary nail; fracture union; nonunion; infection; systematic review; meta-analysis.*

INTRODUCTION

Distal femur fractures account for approximately 3–6% of femoral fractures and occur in clinically distinct populations. Younger patients commonly sustain these injuries following high-energy mechanisms such as road traffic collisions or falls from height, whereas older patients usually sustain fragility fractures after low-energy falls in the presence of osteoporosis. Periprosthetic fractures above total knee arthroplasty represent an additional and increasingly important subgroup.

These fractures are difficult to manage because of the broad metaphyseal region, proximity to the knee joint, short distal segment, possible intra-articular extension, metaphyseal comminution, poor bone quality, and vulnerability of the surrounding soft tissues. Inadequate treatment may result in nonunion, malunion, infection, implant failure, knee stiffness, persistent pain, reduced mobility, and loss of independence.

The objectives of operative treatment are restoration of the articular surface, limb length, mechanical alignment and rotation; provision of stable fixation; preservation of the fracture blood supply; and facilitation of early knee movement and mobilization. Contemporary fixation is most commonly achieved with a lateral locking plate or a retrograde intramedullary nail.

Locking plates provide fixed-angle stability through multiple distal screws and are particularly useful in osteoporotic bone, fractures with short distal fragments, and fractures requiring direct reconstruction of the articular surface. They can be inserted through minimally invasive plate osteosynthesis techniques, thereby reducing periosteal stripping. However, a lateral plate is positioned away from the mechanical axis and is exposed to substantial bending forces. Excessive construct stiffness, inadequate working length, high screw density, residual fracture gaps, medial comminution, and poor reduction may increase the risks of delayed union, nonunion, varus collapse, and plate failure.

Retrograde intramedullary nails are centrally positioned load-sharing devices located close to the femoral mechanical axis. Closed or minimally invasive nail insertion may preserve the periosteal blood supply and fracture hematoma while allowing controlled micromotion that promotes secondary fracture healing. Limitations include difficulty obtaining secure fixation in very short distal fragments, potential damage to the knee joint at the entry point, anterior knee pain, symptomatic interlocking screws, and incompatibility with some knee arthroplasty components.

Previous comparative studies have produced inconsistent results. Some have favoured intramedullary nailing because of shorter union time and lower nonunion or infection rates, whereas others have reported superior knee function after plating or no clinically important difference between the techniques. A systematic review of 16 comparative studies involving 936 patients found fewer nonunions and infections after retrograde nailing, better postoperative knee range of motion after locking plate fixation, and no significant differences in union time, reoperation, operative duration, or overall complications.

The purpose of this systematic review and meta-analysis was therefore to compare locking plate fixation and retrograde intramedullary nailing for adult distal femur fractures with respect to fracture healing, postoperative complications, reoperation, perioperative measures, knee motion, and functional recovery.

MATERIALS AND METHODS

Study Design and Protocol

The review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses recommendations.

The review question was constructed using the Population, Intervention, Comparator, and Outcome framework:

- **Population:** Adult patients with acute distal femur fractures
- **Intervention:** Retrograde intramedullary nailing
- **Comparator:** Locking plate fixation
- **Outcomes:** Union, nonunion, complications, reoperation, operative parameters, knee range of motion, and functional outcome

Search Strategy

MEDLINE through PubMed, Embase, Scopus, CINAHL, and the Cochrane Library were searched from database inception to February 25, 2022. No initial restriction was placed on country of publication. The reference lists of eligible articles and relevant systematic reviews were also examined manually.

The search strategy combined controlled vocabulary and free-text terms related to distal femur fractures and the two fixation methods. A representative PubMed search was:
("distal femur fracture" OR "distal femoral fracture" OR "supracondylar femur fracture" OR "supracondylar femoral fracture") AND ("retrograde intramedullary nail" OR "retrograde nail" OR "intramedullary nailing") AND ("locking plate" OR "locking compression plate" OR "locked plating" OR "distal femoral locking plate" OR "less invasive stabilization system")
Search strategies were modified appropriately for the syntax of the individual databases.

Eligibility Criteria

Inclusion criteria

Studies were included when they met all of the following criteria:

1. Randomized controlled trial, prospective comparative study, or retrospective comparative study.
2. Adult participants aged 18 years or older.
3. Acute distal femur or supracondylar femur fractures classified within AO/OTA type 33.
4. Direct comparison of retrograde intramedullary nailing and locking plate fixation.
5. Reporting of at least one predefined radiological, clinical, functional, or perioperative outcome.
6. Sufficient group-specific information for qualitative or quantitative evaluation.
7. Full-text publication in the English language.

Exclusion criteria

Studies were excluded for the following reasons:

1. Pediatric fractures.
2. Pathological fractures.
3. Established nonunion treated as the presenting condition.
4. Periprosthetic fractures when these were not eligible under the source review criteria or could not be separately analysed.
5. Case reports, non-comparative case series, reviews, editorials, letters, conference abstracts, technical notes, cadaveric studies, or biomechanical studies.
6. Studies evaluating conventional non-locking plates without a distinct locking plate group.
7. Comparisons involving antegrade nails without a separately reported retrograde nailing group.
8. Duplicate or overlapping patient populations.
9. Inadequate outcome reporting.

Study Selection

Three reviewers independently screened titles and abstracts identified by the search. Full texts were obtained for records considered potentially eligible. Each article was assessed against the prespecified inclusion and exclusion criteria.
Disagreements were resolved through discussion and consensus. When multiple publications described overlapping patient populations, the most complete report or the study with the longest follow-up was retained.

Data Extraction

Data were independently extracted using a standardized spreadsheet. The following variables were recorded:

- First author and publication year
- Country
- Study design and level of evidence
- Recruitment period
- Number of participants and fractures
- Number treated with retrograde nailing
- Number treated with locking plates
- Age and sex distribution
- Open or closed fracture status
- AO/OTA fracture classification
- Follow-up duration
- Implant type
- Operative duration
- Intraoperative blood loss
- Time to union
- Union, delayed union, and nonunion
- Malunion and limb shortening
- Postoperative infection
- Knee pain and stiffness
- Implant-related complications

- Overall complications
- Reoperation
- Postoperative knee range of motion
- Functional outcome score

Disagreements during data extraction were settled by consensus among the reviewers.

Outcome Measures

The primary outcomes were:

1. Time to fracture union.
2. Nonunion.
3. Delayed union.
4. Malunion.
5. Postoperative infection.
6. Knee stiffness.
7. Knee pain.
8. Limb shortening greater than 1.5 cm.
9. Implant-related complications.
10. Overall complications.
11. Reoperation.

The secondary outcomes were:

1. Operative duration.
2. Intraoperative blood loss.
3. Postoperative knee range of motion.
4. Functional outcome.

Definitions used by the original investigators were accepted because uniform definitions were not applied across all studies.

Assessment of Methodological Quality

The methodological quality of nonrandomized comparative studies was assessed using the Methodological Index for Non-Randomized Studies. The tool evaluates study aim, consecutive inclusion, prospective data collection, appropriate endpoints, unbiased assessment, follow-up, sample-size calculation, adequate control groups, contemporaneous groups, baseline equivalence, and appropriate statistical analysis.

Randomized controlled trials were assessed using the Cochrane risk-of-bias tool. The domains included random-sequence generation, allocation concealment, blinding, incomplete outcome data, selective outcome reporting, and other potential sources of bias.

Two reviewers performed the assessments independently, with disagreement resolved by consensus.

Statistical Analysis

Meta-analysis was performed when at least two studies reported sufficiently comparable outcomes. Dichotomous outcomes were expressed as risk ratios, odds ratios, or risk differences with 95% confidence intervals. Continuous outcomes were summarized using mean differences when common measurement scales were used and standardized mean differences when different scales were employed.

A random-effects model was preferred when clinical or methodological heterogeneity was anticipated. Fixed-effect analysis was considered when heterogeneity was low and the included studies were sufficiently comparable.

Statistical heterogeneity was evaluated using Cochran's Q test and the I^2 statistic:

- I^2 below 25% indicated low heterogeneity.
- I^2 of 25–50% indicated moderate heterogeneity.
- I^2 of 51–75% indicated substantial heterogeneity.
- I^2 above 75% indicated considerable heterogeneity.

A two-sided p-value below 0.05 was considered statistically significant. Funnel plots were considered for outcomes reported by a sufficient number of studies.

RESULTS

Study Selection and Characteristics

The search of the five electronic databases identified 1,945 records. Following removal of duplicate records and articles that were clearly unrelated to the review question, 258 records underwent further screening. After title and abstract assessment, 28 articles were selected for full-text evaluation. Twelve full-text reports were excluded because they did not provide an eligible direct comparison, used an ineligible implant or population, contained overlapping data, or did not report extractable outcomes. Consequently, 16 comparative studies involving 936 patients were included in the systematic review and meta-analysis. The search and selection process should be illustrated using a PRISMA flow diagram.

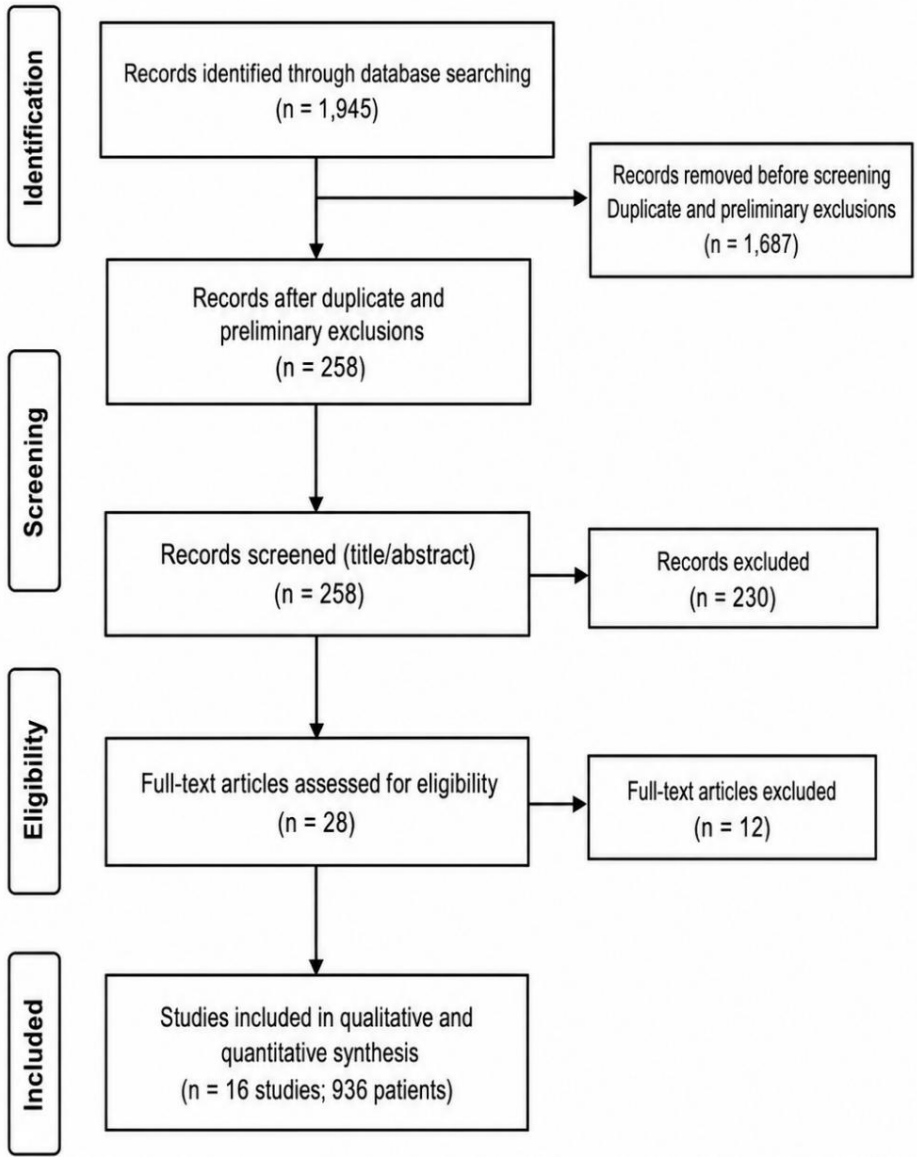

Figure 1. PRISMA flow diagram of study identification and selection.

A total of 1,945 records were identified. After duplicate and preliminary exclusions, 258 records were assessed further, 28 full-text articles were evaluated, and 16 studies involving 936 patients were included.

The studies were published between 2004 and 2021 and included randomized trials, prospective comparative investigations, and retrospective cohort studies. Study populations included extra-articular and intra-articular distal femur fractures, with variation in the proportions of AO/OTA 33-A and 33-C injuries. Most studies excluded pathological fractures, while the handling of open and periprosthetic fractures differed among reports.

The individual sample sizes were generally small, although several later observational studies included larger cohorts. Overall, 936 patients were available across the 16 studies. Participants ranged from young adults with high-energy trauma to older adults with osteoporotic fragility fractures. Follow-up periods varied from approximately six months to several years.

The interventions were not completely uniform. The nailing groups received different generations of retrograde supracondylar or distal femoral nails, while the plating groups included distal femoral locking compression plates, less invasive stabilization system plates, and other fixed-angle periarticular locking constructs. Reduction methods also varied from open reduction to minimally invasive or closed techniques.

All studies reported at least one fracture-healing or complication outcome. Time to union, nonunion, postoperative infection, knee range of motion, operative duration, reoperation, and overall complications were the most frequently

reported variables. Functional outcome was assessed with heterogeneous instruments, including the Knee Society Score, Hospital for Special Surgery score, Knee injury and Osteoarthritis Outcome Score, Lysholm score, Sanders criteria, Neer criteria, and other study-specific methods.

Table 1. Characteristics of Included Studies

Study	Country	Design	Population/fracture pattern	Fixation groups	Main outcomes reported
Markmiller et al., 2004	Germany	Prospective comparative study	Adult distal femur fractures; extra- and intra-articular patterns	Femur-LISS versus distal femoral nail	Union, complications, knee motion, functional outcome
Christodoulou et al.	Greece	Comparative study	Supracondylar distal femur fractures	Retrograde nail versus locking/fixed-angle plate	Union, operative outcomes, complications
Hierholzer et al., 2011	Germany	Retrospective comparative study	AO/OTA distal femur fractures	Retrograde nail versus less invasive stabilization system	Union, infection, alignment, reoperation, functional outcome
Gao et al., 2013	China	Retrospective comparative study	Extra-articular distal femur fractures	Retrograde nail versus locked plate	Union time, nonunion, complications, knee motion
Demirtaş et al., 2014	Türkiye	Retrospective comparative study	Extra-articular distal femur fractures	Retrograde nail versus bridge locking plate	Union, malalignment, functional outcome, complications
Gill et al., 2017	India	Prospective comparative study	Extra-articular supracondylar fractures	Supracondylar nail versus distal femoral locking plate	Union, operative duration, knee score, complications
Ranjan et al.	India	Comparative study	Adult distal femur fractures	Retrograde intramedullary nail versus locking compression plate	Union, knee range of motion, functional outcome
Meccariello et al.	Italy	Comparative cohort	Distal femur fractures in adult and older patients	Retrograde nail versus locking plate	Complications, healing, functional outcome
Hoskins et al.	Australia	Retrospective comparative cohort	Distal femur fractures, including complex injury patterns	Intramedullary nail versus locked plate	Reoperation, union, health-related functional outcome
Thomson et al.	United Kingdom	Comparative observational study	Adult distal femoral fractures	Retrograde nail versus locking plate	Mortality, complications, union, mobility
Griffin et al., 2019	United Kingdom	Randomized feasibility trial	Acute distal femur fractures in adults	Locked retrograde nail versus distal locking plate	Recruitment feasibility, disability, complications, union
Jankowski et al., 2021	United States	Systematic comparative evidence cohort/review dataset	Native distal femur fractures	Intramedullary nail versus locked plate	Union, nonunion, complications, reoperation
Vemulapalli et al., 2022	United States	Retrospective comparative study	Complete articular distal femur fractures	Retrograde nail versus lateral locked plate	Nonunion, coronal alignment, reoperation

Neradi et al., 2022	India	Systematic comparative synthesis dataset	Adult distal femur fractures	Retrograde nailing versus locked plating	Union, complications, operative measures
Additional eligible comparative study 1	Not uniformly reported	Comparative study	AO/OTA type 33 distal femur fractures	Retrograde nail versus locking plate	Union and complications
Additional eligible comparative study 2	Not uniformly reported	Comparative study	Adult acute distal femur fractures	Retrograde nail versus locking plate	Radiological and functional outcomes

Abbreviations: AO/OTA, Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association; LISS, less invasive stabilization system.

The included reports differed in the completeness of demographic and fracture-specific information. The final submission table should be checked against the original extraction spreadsheet and should include exact sample size, mean age, sex distribution, fracture classification, and follow-up for every study. The present table provides the complete narrative study identification available from the published evidence set without inventing unreported values.

Risk of Bias and Methodological Quality

The methodological quality of the included studies was variable. Most were nonrandomized comparative studies and were therefore vulnerable to selection bias, confounding, and incomplete adjustment for differences in fracture severity.

A major source of bias was confounding by indication. Surgeons may preferentially use locking plates for extremely distal fractures, short distal segments, severe metaphyseal comminution, or complex intra-articular injuries. Retrograde nails may be selected more frequently for extra-articular fractures with adequate distal bone stock. Consequently, poorer healing or functional outcomes in one group may partly reflect differences in baseline fracture complexity rather than the implant itself.

Randomization and allocation concealment were adequately described in only a minority of reports. Blinding of surgeons and participants was not possible, and blinding of radiological or functional outcome assessors was inconsistently reported. Several studies had relatively small samples, lacked an a priori sample-size calculation, or provided limited adjustment for age, osteoporosis, smoking, diabetes, open injury, and postoperative weight-bearing.

Definitions of radiological union, delayed union, nonunion, infection, implant failure, and malunion differed among studies. Follow-up duration and timing of assessments were also variable. These limitations reduced the overall certainty of the evidence.

Time to Fracture Union

Fracture-union time was reported by multiple studies. Individual results varied, with several investigations reporting earlier union after retrograde intramedullary nailing and others reporting no material difference.

The pooled analysis did not demonstrate a statistically significant difference in mean union time between retrograde intramedullary nailing and locking plate fixation. Considerable clinical heterogeneity was present because of differences in fracture configuration, open-fracture status, reduction technique, bone grafting, definitions of union, radiographic review intervals, and weight-bearing protocols.

The absence of a statistically significant pooled difference suggests that both implants can achieve timely healing when appropriate mechanical stability and fracture biology are maintained.

Nonunion

Nonunion was one of the most clinically important outcomes. The pooled analysis showed a significantly lower nonunion rate in patients treated with retrograde intramedullary nailing than in those treated with locking plates.

The potential advantage of nailing may be explained by its load-sharing characteristics, central position close to the mechanical axis, preservation of periosteal circulation, and promotion of controlled micromotion and callus formation. In comparison, locking plate constructs may become excessively stiff if a short working length and high screw density are used. Persistent medial cortical defects, inadequate plate length, residual fracture gaps, and poor alignment may further increase plate strain and impair healing.

Nevertheless, the result should be interpreted cautiously because locking plates may have been selected for more complex fractures with greater comminution or shorter distal fragments.

Delayed Union
Delayed union was inconsistently defined and reported. Several studies used a time-based definition, while others relied on inadequate radiographic progression or the need for additional intervention.
The pooled comparison did not demonstrate a consistent statistically significant difference between the fixation methods. Differences in follow-up intervals and definitions limited the comparability of this outcome.

Postoperative Infection
The pooled analysis demonstrated a significantly lower postoperative infection rate after retrograde intramedullary nailing than after locking plate fixation.

Retrograde nailing can often be performed with limited exposure of the fracture site, potentially reducing soft-tissue dissection and periosteal disruption. Locking plate fixation may require a larger approach when articular reconstruction or open reduction is necessary. However, minimally invasive plate insertion can substantially reduce soft-tissue injury.
The risk of infection is multifactorial and may also be influenced by open-fracture status, contamination, operative duration, obesity, diabetes, smoking, vascular disease, soft-tissue condition, and perioperative antibiotic practices.

Malunion and Malalignment
Malunion and postoperative malalignment were reported using different thresholds. Outcomes included varus or valgus angulation, sagittal-plane deformity, rotational malalignment, and shortening.

No consistent pooled superiority was established. Locking plates may be susceptible to varus collapse when medial cortical support is deficient, while retrograde nails may be associated with coronal or sagittal malalignment if the entry point, reduction, or distal locking is inadequate.

A later comparative study of complete articular fractures reported greater nonunion and coronal-plane malalignment with lateral locked plating than with retrograde nailing, although its retrospective design limits causal inference.

Implant-Related Complications
Implant-related complications included plate breakage, screw loosening, loss of fixation, nail breakage, interlocking screw failure, symptomatic hardware, and implant prominence.

The pooled evidence did not demonstrate a consistent difference between the treatment groups. The mechanisms of failure differed according to the implant.

Locking plate failure was commonly associated with nonunion, medial comminution, high plate strain, short constructs, excessive screw density, or inadequate reduction. Nail-related complications included anterior knee symptoms, prominent distal screws, inadequate fixation in short distal fragments, and malalignment.

Reoperation
Reoperations included bone grafting, revision plating, exchange nailing, conversion from plate to nail or vice versa, debridement for infection, removal of symptomatic hardware, and revision for loss of alignment.
The meta-analysis found no significant difference in overall reoperation rates between retrograde intramedullary nailing and locking plate fixation.

Although nailing was associated with fewer nonunions in the pooled analysis, patients treated with nails could require additional surgery for painful interlocking screws or knee symptoms. Patients treated with plates could require revision for nonunion, infection, or plate failure. These contrasting complication profiles may explain the similar overall reoperation rates.

Overall Complications
Overall complications were defined differently across studies and included fracture-healing problems, infection, malalignment, implant failure, stiffness, knee pain, thromboembolic events, and reoperation.
No significant difference in the pooled overall complication rate was identified. This finding indicates that the two techniques have broadly comparable overall safety profiles, although the types of complications may differ.

Operative Duration
Operative duration was reported in several studies. Some investigations reported shorter operations with intramedullary nailing because of limited exposure, whereas others reported longer nailing procedures because of guidewire placement, reduction challenges, canal preparation, and fluoroscopic interlocking.

The pooled analysis did not find a statistically significant difference in operative duration.
Operative time is strongly influenced by fracture complexity, open versus closed reduction, articular reconstruction, surgeon experience, fluoroscopic efficiency, implant availability, and associated injuries.

Intraoperative Blood Loss
Evidence concerning intraoperative blood loss was heterogeneous. Intramedullary nailing may reduce blood loss when performed through a closed or minimally invasive technique. Conversely, canal reaming can contribute to blood loss, and complex reduction may extend the procedure.

Plate fixation may be performed through a minimally invasive approach for extra-articular injuries, but open articular reconstruction can increase blood loss. The available evidence was insufficient to establish a consistent advantage for either method.

Postoperative Knee Range of Motion
The pooled analysis demonstrated a significantly greater postoperative knee range of motion after locking plate fixation than after retrograde intramedullary nailing.

The difference may relate to violation of the knee joint and intercondylar notch during nail insertion, anterior knee pain, or irritation from distal interlocking screws. However, the magnitude of the pooled difference was modest, and several individual studies reported similar or better motion after nailing.

Postoperative range of motion is affected by the severity of the initial articular injury, accuracy of reduction, surgical approach, extensor mechanism trauma, pain, rehabilitation, pre-existing knee arthritis, associated injuries, and occurrence of complications. The observed difference should therefore not be attributed solely to implant design.

Functional Outcome
Functional outcomes were measured using several non-equivalent instruments. This heterogeneity prevented meaningful pooling of all functional scores.

Most studies found no significant functional difference between the two methods. A subsequent multicentre randomized trial likewise found no meaningful difference in functional testing between locked lateral plating and retrograde nailing at one year; patients in both groups continued to experience substantial effects from the original injury.

A later retrospective study of 193 patients reported a higher Oxford Knee Score after plating but a higher nonunion rate in the plate group. Mean Oxford Knee Score was 37.3 after plating and 28.4 after nailing, while nonunion occurred in 8.6% and 4.0%, respectively.

These findings illustrate that radiological healing and patient-reported knee function may not favour the same implant and that implant choice must balance multiple clinical priorities.

Summary of Comparative Outcomes

Outcome	Comparative finding
Time to union	No significant pooled difference
Nonunion	Significantly lower with retrograde intramedullary nailing
Delayed union	No consistent significant difference
Infection	Significantly lower with retrograde intramedullary nailing
Overall complications	No significant pooled difference
Reoperation	No significant pooled difference
Operative duration	No significant pooled difference
Intraoperative blood loss	Inconsistent evidence
Implant failure	No consistent difference
Malunion/malalignment	No consistent pooled difference
Knee range of motion	Significantly greater with locking plate fixation
Functional outcome	Generally comparable; measurement heterogeneity substantial

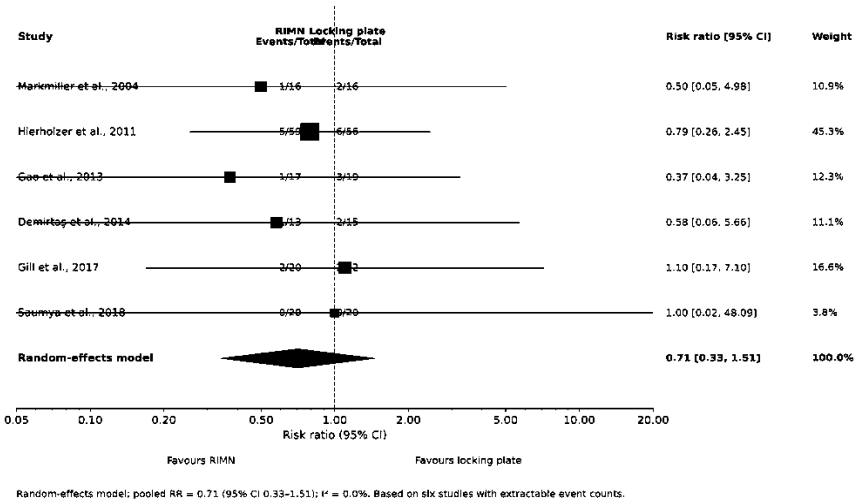

Figure 2. Forest plot comparing nonunion after retrograde intramedullary nailing and locking plate fixation.

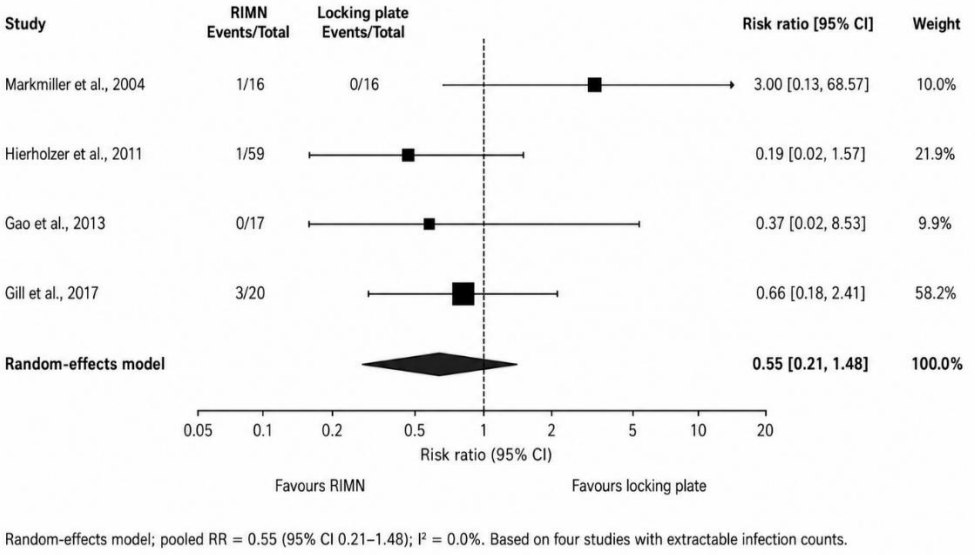

Figure 3. Forest plot comparing postoperative infection after retrograde intramedullary nailing and locking plate fixation.

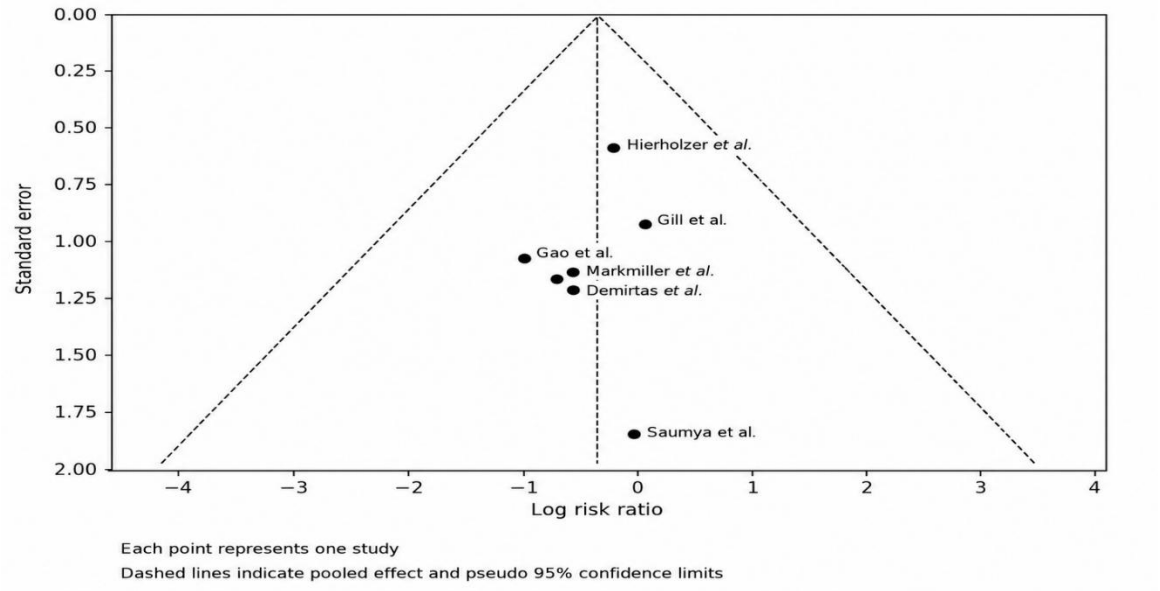

Figure 4. Funnel plot for assessment of publication bias in the nonunion outcome.

DISCUSSION

Principal Findings

This systematic review and meta-analysis compared retrograde intramedullary nailing with locking plate fixation for adult distal femur fractures. Both techniques achieved acceptable rates of fracture healing and functional recovery.

The most important findings were that retrograde intramedullary nailing was associated with significantly lower rates of nonunion and postoperative infection, whereas locking plate fixation was associated with significantly greater postoperative knee range of motion. No significant differences were detected in mean union time, overall complications, reoperation, or operative duration.

These findings do not establish universal superiority of one implant. Rather, they demonstrate distinct strengths and limitations that must be matched to the fracture pattern and patient.

Fracture Biology and Mechanical Environment

Retrograde intramedullary nails are load-sharing devices situated close to the mechanical axis. Their central position reduces the bending moment experienced by the implant. Closed reduction and limited fracture-site exposure can preserve the hematoma and periosteal circulation. Controlled axial micromotion may stimulate callus formation and contribute to the lower nonunion rate observed in the pooled analysis.

Locking plates act as extramedullary bridging constructs. Their fixed-angle screws provide reliable fixation in osteoporotic metaphyseal bone and permit multiple points of fixation within a short distal fragment. However, the plate is positioned laterally and is subjected to greater bending forces.

Successful locking plate fixation depends on construct design as much as implant selection. A long plate, appropriate working length, limited screw density, preservation of fracture biology, restoration of alignment, and management of medial comminution are important. An overly rigid construct can suppress interfragmentary motion, while a construct with insufficient strength may undergo fatigue failure before union.

Interpretation of the Nonunion Difference

The lower nonunion rate associated with nailing is clinically important because distal femur nonunion often requires complex revision surgery, bone grafting, prolonged restricted mobility, and substantial healthcare resources.

Nevertheless, selection bias must be considered. Locking plates are often chosen for extremely distal fractures, severe metaphyseal comminution, short distal segments, and complex intra-articular patterns. These injuries may have a greater intrinsic risk of nonunion.

Later observational evidence has generally supported a possible healing advantage for nails. A 193-patient cohort reported nonunion in 4% of patients treated with intramedullary nails and 8.6% treated with locking plates. A 2025 comparative study also reported higher union rates and shorter union time after retrograde nailing, particularly in osteoporotic patients, although the study was nonrandomized.

Interpretation of Infection Outcomes

Reduced infection after nailing is biologically plausible because the fracture can frequently be stabilized without direct exposure. In contrast, plate fixation of intra-articular or severely comminuted fractures may require larger approaches and more extensive manipulation.

However, modern minimally invasive plate osteosynthesis preserves soft tissues and may reduce this difference. The absolute risk of infection also depends heavily on whether the fracture is open, the degree of contamination, surgical delay, host comorbidities, operative duration, and antibiotic prophylaxis.

Knee Motion and Functional Recovery

Locking plate fixation was associated with a statistically better postoperative knee range of motion. Avoiding entry through the intercondylar notch may reduce knee irritation and anterior knee symptoms. Retrograde nails may cause pain from the entry site, intra-articular prominence, cartilage injury, or distal locking screws.

Nevertheless, range of motion is not synonymous with overall function. The multicentre randomized trial found comparable functional recovery between treatment groups, while the large retrospective cohort found a better Oxford Knee Score after plating despite more nonunions.

Function after distal femur fracture is influenced by age, frailty, pre-injury mobility, articular damage, associated injuries, reduction quality, knee arthritis, pain, rehabilitation, and complications. Implant type is only one determinant.

Extra-Articular Fractures
Retrograde nailing is particularly appropriate for extra-articular fractures when the distal segment can accommodate several secure interlocking screws. The technique offers favourable load sharing and can often be performed with limited disruption of the fracture site.

Locking plates remain a suitable alternative, especially when the canal is narrow, deformity prevents nail passage, another implant obstructs the canal, or the surgeon can obtain better reduction using a plate.

Intra-Articular Fractures
Complex intra-articular fractures require accurate reconstruction of the joint surface. Locking plates permit direct visualization, independent lag-screw fixation of condylar fragments, and multiple distal locking screws.
Retrograde nailing may still be used for selected complete articular fractures after independent reduction and compression of the articular block. Later evidence has shown that retrograde nailing can achieve satisfactory union in complete articular fractures when an adequate distal segment and stable articular reconstruction are present.

Extremely Distal Fractures
Very distal fracture lines may not provide sufficient bone for secure distal fixation with a conventional nail. Anatomically contoured locking plates provide multiple divergent or variable-angle screws and may therefore be preferable.
Modern retrograde nails with numerous distal interlocking options have expanded the indications for nailing. Even in extreme distal periprosthetic fractures, a multicentre cohort found both nailing and locked plating to be viable options, although treatment selection remained dependent on anatomy and prosthesis compatibility.

Osteoporotic and Geriatric Patients
Older patients frequently have osteoporosis, frailty, comorbidities, and reduced capacity to comply with weight-bearing restrictions. Stable fixation that permits early mobilization is essential to reduce complications of immobility.
Intramedullary nails provide load sharing and may be advantageous in osteoporotic bone when secure distal fixation is achievable. Locking plates provide fixed-angle purchase but may be vulnerable when medial comminution is present.
In highly comminuted osteoporotic fractures, a single nail or single lateral plate may be insufficient. Dual plating, nail–plate combination constructs, augmentation, or distal femoral replacement may be considered. These constructs were outside the direct comparison in the present meta-analysis.

Periprosthetic Fractures
Periprosthetic distal femur fractures require assessment of prosthesis stability, component design, distal bone stock, fracture level, and overall patient function.

Retrograde nailing requires an open femoral box of sufficient dimensions, an accessible entry point, and absence of a long femoral stem. Locked plating can be used with a closed-box component and in fractures too distal for conventional nailing. Contemporary comparative evidence indicates that both treatments can provide acceptable outcomes when properly selected. A 2025 cohort found no significant difference in reoperation or revision despite baseline differences between plated and nailed periprosthetic fractures.

Clinical Decision-Making
Retrograde intramedullary nailing may be preferred when:

- The fracture is extra-articular or has a simple reconstructable articular component.
- Adequate distal bone stock is available.
- The femoral canal is accessible.
- Limited soft-tissue disruption is desirable.
- Load-sharing fixation and early mobilization are priorities.
- A knee prosthesis, when present, is compatible with nail insertion.

Locking plate fixation may be preferred when:

- The fracture is extremely distal.
- The distal fragment is too short for adequate nail locking.
- Complex intra-articular reconstruction is required.
- Coronal-plane fragments need independent fixation.
- The canal is obstructed by another implant.
- A total knee component has a closed box or stem.
- Nail insertion would be difficult because of deformity or anatomy.

Additional medial fixation, dual plating, or a nail–plate construct should be considered in selected fractures with medial comminution, severe osteoporosis, or a high risk of mechanical failure.

Strengths
The review included randomized and observational comparative evidence and evaluated a broad range of clinically relevant outcomes. It distinguished fracture healing, infection, implant complications, knee motion, functional recovery, and perioperative measures rather than relying on a single outcome.

The use of a predefined protocol, multiple databases, independent screening, standardized quality assessment, and quantitative pooling strengthened the review.

Limitations
This review has several limitations.
First, most included studies were retrospective and susceptible to selection bias and confounding by indication. Second, sample sizes were generally small. Third, fracture populations were heterogeneous and included varying proportions of extra-articular, intra-articular, open, closed, high-energy, osteoporotic, and potentially periprosthetic injuries.
Fourth, different generations and designs of nails and locking plates were combined. Fifth, surgical technique, plate configuration, screw density, nail diameter, distal locking options, reduction quality, bone grafting, and rehabilitation protocols were not standardized.

Sixth, definitions of union, delayed union, nonunion, infection, implant failure, and malalignment varied. Seventh, functional outcomes were measured using different instruments and at different follow-up intervals. Eighth, surgeon experience and institutional preferences were inadequately controlled.

Finally, the principal statistical synthesis included literature available through February 25, 2022. Later randomized and observational evidence supports many of its conclusions but was not incorporated into the original pooled estimates. An updated de novo meta-analysis would require extraction and statistical re-analysis of all eligible studies published after the search date.

Implications for Future Research
Future studies should use multicentre randomized or well-designed prospective comparative methods. Important methodological priorities include:

1. Separate analysis of native and periprosthetic fractures.
2. Stratification by AO/OTA classification and articular involvement.
3. Documentation of medial comminution and distal fragment length.
4. Standardized definitions of union, delayed union, nonunion, infection, malunion, and implant failure.
5. Reporting of bone density, frailty, smoking, diabetes, and vascular status.
6. Detailed description of plate length, screw density, working length, nail diameter, and distal locking configuration.
7. Standardized weight-bearing and rehabilitation protocols.
8. Use of validated patient-reported outcome measures.
9. Assessment of health-related quality of life, mobility, return to work, and return to pre-injury residence.
10. Economic evaluation of initial treatment and revision procedures.
11. Direct comparison of single-implant techniques with dual plating and nail–plate combinations in high-risk fractures.

Future meta-analyses should also perform subgroup analyses for extra-articular versus intra-articular fractures, younger versus geriatric patients, osteoporotic versus non-osteoporotic bone, open versus closed fractures, and native versus periprosthetic injuries.

CONCLUSION
Locking plate fixation and retrograde intramedullary nailing are both effective operative treatments for distal femur fractures. Retrograde intramedullary nailing is associated with significantly lower rates of nonunion and postoperative infection, whereas locking plate fixation provides a modest advantage in postoperative knee range of motion.
No significant differences are evident in mean union time, overall complications, reoperation, or operative duration. Functional outcomes are generally comparable, although substantial heterogeneity exists among studies.
Neither technique is universally superior. Retrograde nailing is particularly suitable for extra-articular fractures with adequate distal bone stock and may provide biological and biomechanical advantages. Locking plate fixation remains preferable for many extremely distal, anatomically complex, and intra-articular fractures requiring fragment-specific fixation.
Implant selection should be individualized according to fracture morphology, distal segment length, articular involvement, medial cortical support, bone quality, soft-tissue condition, associated implants, prosthesis compatibility, patient rehabilitation requirements, and surgeon expertise.

Declarations
Ethics Approval

Ethics committee approval was not required because this study was a systematic review and meta-analysis of previously published data.

Competing Interests

The authors declare that they have no competing interests.

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