AUGMENTED INTERNAL FIXATION OF DISTAL FEMORAL FRACTURES: CURRENT CONCEPTS, BIOMECHANICAL RATIONALE, INDICATIONS, AND CLINICAL EVIDENCE-A REVIEW

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Abstract-Distal femoral fractures remain difficult to treat, particularly in older patients with poor bone quality and in highly comminuted injuries with loss of medial cortical support. Objective: To review the biomechanical rationale, indications, techniques, and reported outcomes of augmented internal fixation. Methods: A focused review of English-language clinical studies, biomechanical investigations, systematic reviews, and meta-analyses was undertaken. PubMed/MEDLINE and ScienceDirect were searched using terms related to distal femoral fractures and augmentation; reference lists were screened for additional relevant publications. Results: The literature identifies poor bone quality, medial comminution or bone loss, and suboptimal construct configuration as major contributors to fixation failure. Reported augmentation strategies include polymethyl methacrylate cement, supplementary medial plating, nail–plate constructs, and structural allografts. These methods may improve construct stability and support earlier rehabilitation in selected high-risk fractures, although the evidence is heterogeneous and largely based on biomechanical studies and clinical case series. Conclusion: Augmentation should be individualized according to host biology, fracture morphology, bone stock, and fixation stability. Comparative clinical evidence remains limited.

Keywords-distal femoral fracture, double plating, cement augmentation, nail–plate construct, biomechanics, osteoporosis, medial column, varus collapse

1. Introduction

In the context of global population aging and increasing life expectancy, the incidence of distal femoral fractures continues to rise. Distal femoral fractures account for 3-6% of all femoral fractures. Less than 10% of distal femoral fractures are comminuted.[1,2,3,4] Patients sustaining distal femoral fractures are increasingly older, with more than half of these injuries occurring in individuals over 60 years of age.[5,6,7] These injuries are typically low-energy fractures occurring on a background of compromised bone quality.[6,8,9,10] In young patients, high-energy trauma dominates, so the primary clinical challenge is managing fracture comminution and the associated soft tissue compromise[1] Although historically overshadowed by proximal femoral fractures, current data demonstrate that distal femoral fractures have an equally significant impact on morbidity and mortality. [11] Consequently, they demand the same level of clinical priority and urgency as hip fractures. [9] The contemporary standard of fixation relies on the use of a single lateral locking compression plate (LCP). However, it does not always provide

sufficient stability for the duration required to achieve bone union. Complication rates remain significant, with nonunion reaching up to 14.8%, malunion 13%, fixation failure 5%, and deep infection up to 3.7%. [6,12,13,14] Despite the increasing use of supplementary fixation, no consensus exists regarding when a single lateral locked plate should be augmented, which augmentation strategy is preferable, or whether biomechanical advantages consistently translate into improved clinical outcomes. This review critically examines the biomechanical rationale, indications, clinical evidence, and limitations of cement augmentation, dual plating, nail–plate constructs, and structural allografts.

2. Materials and Methods

A structured literature search was conducted in PubMed and ScienceDirect to identify relevant English-language publications on augmented internal fixation of distal femoral fractures. Search terms were used individually and in combination and included "distal femur fracture," "distal femoral fracture," "augmentation," "dual plating," "double plating," "medial plate," "cement augmentation," "polymethyl methacrylate (PMMA)," "nail-plate construct," "plate-nail construct," "structural allograft," "osteoporosis," "biomechanics," "nonunion," and "early weight-bearing." The reference lists of relevant publications were also screened manually to identify additional sources.

Eligibility and Study Selection

Publications were selected according to their relevance to the objectives of the review. Eligible evidence included original clinical studies, biomechanical and cadaveric investigations, systematic reviews, meta-analyses, and relevant review articles concerning adult patients with native or periprosthetic distal femoral fractures (AO/OTA types 33-A, 33-B, and 33-C). Studies were considered when they addressed the biomechanical rationale, indications, techniques, or clinical outcomes of supplementary fixation using cement augmentation, an additional medial plate, a nail–plate construct, or a structural allograft. Publications focusing exclusively on pediatric fractures, pathological fractures, or non-operative treatment were outside the scope of the review. Study selection was guided by relevance to the review question and the contribution of each publication to the biomechanical or clinical synthesis. Higher-level and comparative evidence was prioritized when available, while technical reports and case-based evidence were considered when they described distinct augmentation strategies not adequately represented in larger studies.

Data Synthesis

The selected literature was reviewed thematically and organized according to the principal augmentation strategies: cement augmentation, dual plating, nail-plate constructs, and structural allografts. The synthesis focused on biomechanical principles, indications for augmentation, construct stiffness and load sharing, medial column support, the screw-bone interface, fracture union and time to union, mechanical complications such as varus collapse and implant failure, postoperative complications, weight-bearing, and functional outcomes. The strength and limitations of the available evidence were appraised qualitatively, taking into account study design, sample size, the presence of a comparator group, and consistency of findings across studies. Given the

heterogeneity of the included studies in terms of design, fracture patterns, augmentation techniques, and reported outcomes, a qualitative synthesis was undertaken rather than a meta-analysis.

Evolution of Conventional and Modern Fixation Systems

The historical approach to the management of distal femoral fractures has undergone a fundamental evolution, transitioning from strictly conservative treatment to modern, highly advanced methods of internal fixation. Prior to 1960, skeletal traction was the treatment of choice. At that time, numerous authors advocated for closed, non-operative management due to the poor functional outcomes and high complication rates associated with ORIF (open reduction and internal fixation). In the 1960s, the introduction of angled blade plates, followed by dynamic condylar screw (DCS) plates, significantly improved the results. Later, in the 1990s, ORIF became established as the standard of care. By the early 2000s, the introduction of early-generation lateral locking plates led to further improvements in final clinical outcomes.[15]

Condylar Blade Plate

Prior to the advent of the Less Invasive Stabilization System (LISS) and locking plate technology, the condylar blade plate was the primary instrumentation for the stabilization of the distal femur. It is characterized by high mechanical strength but demands meticulous surgical precision and is associated with a steep learning curve. The technical challenge lies in the accurate, simultaneous triplanar positioning of the implant (coronal, sagittal, and rotational planes). A deviation in the angle of insertion by even a few degrees results in irreversible bony malalignment (varus/valgus or flexion/extension deformities). Furthermore, the procedure typically necessitates an extensive surgical exposure and significant soft-tissue stripping, which subsequently compromises and delays fracture healing.[15]

Dynamic Condylar Screw (DCS)

Based on the operating principles of the dynamic hip screw (DHS), this implant was designed as a technically more forgiving and adaptable alternative to the condylar blade plate. A key biomechanical advantage of the DCS is its ability to facilitate controlled interfragmentary compression through the sliding mechanism of the lag screw within the plate barrel. Furthermore, its surgical application is less technically demanding because intraoperative alignment requires correction in only two planes (biplanar adjustment). The large thread diameter of the condylar screw also ensures enhanced purchase and stable fixation within osteoporotic bone. However the construct is bulky, which may lead to postoperative soft-tissue irritation and chronic pain due to the disrupted condylar anatomy. [6,16]

Condylar Buttress Plate (CBP)

The condylar buttress plate is optimized for intra-articular fractures (AO/OTA type B). The plate functions as a mechanical buttress, physically preventing proximal displacement of the fracture fragment under the influence of muscular forces and axial loading. Fixation relies on the insertion of multiple lag screws, which pass through the

plate and across the fracture line to achieve interfragmentary compression, securing the fragment against the main bone stock and restoring the articular surface. Unlike LISS or LCP systems, the condylar buttress plate is not a fixed-angle device. Construct stability depends entirely on the friction generated between the plate and the bone surface via torque from screw tightening. Consequently, in the presence of poor bone quality, screw loosening may occur.[16] In contemporary practice, the condylar buttress plate has been almost completely superseded by Locking Compression Plates (LCP).

Locking Compression Plate and Less Invasive Stabilization System

Currently, the lateral locking compression plate (LCP/LISS) is the implant of choice for the fixation of distal femoral fractures. It is anatomically pre-contoured and can serve as a template to restore proper anatomical alignment. Another advantage of the LCP is its suitability for minimally invasive insertion, which preserves the surrounding soft-tissue envelope and maintains local vascularity. The LISS system acts as an "internal fixator" that effectively maintains limb length and rotation without causing periosteal compression or compromising the osseous blood supply.[6,16,17]

However, despite initial clinical enthusiasm, subsequent studies have uncovered several implant-specific complications.[18] For instance, Lujan et al. reported deficient and asymmetric callus formation at six months postoperatively in as many as 37% of fractures. The authors attributed this phenomenon to the excessive structural rigidity of the locking plate construct, coupled with the unilateral nature of the fixation.[17] Furthermore, in a large-scale prospective study, Rodriguez et al. reported a concerning 10% rate of bone nonunion (pseudoarthrosis). Nonunion rates of up to 20% have also been documented.[19]

In the absence of an intact medial cortex (due to a medial defect or comminution), the entire mechanical load is transferred directly to the plate. This leads to metal fatigue and an increased risk of implant failure (hardware breakage) at the fracture site.[20] Excessive construct rigidity can be counterproductive. If the construct is overly rigid, it induces the phenomenon of "stress shielding," wherein the implant absorbs the entirety of the mechanical stress, thereby depriving the bone of the physiological stimuli necessary for regeneration.[21] This lack of mechanical stimulus results in the delayed formation of new bone matrix. To activate secondary callus formation, a specific level of interfragmentary strain is required. Excessively rigid fixation inhibits this process, consequently leading to delayed union.[22,23,24]

Retrograde Intramedullary Nail (rIMN)

In this technique, the nail is inserted through the intercondylar notch of the knee and positioned within the medullary canal of the femur. Unlike plates, which are an eccentric implant, it is a centramedullary load-sharing device that distributes the mechanical forces between the metal and the bone. This biomechanical environment stimulates more rapid callus formation. Furthermore, the procedure is minimally invasive and preserves the periosteal blood supply at the fracture site.[16]

Despite providing stable diaphyseal fixation, the system exhibits critical weaknesses in the distal segment. The distal femur is wide and features a large, funnel-shaped medullary cavity. Because the nail is narrower than the canal in this region, it may fail to achieve adequate cortical contact. This can result in the loosening of interlocking screws and subsequent loss of reduction. In cases of comminuted intra-articular fractures (AO/OTA type 33-C3), the nail frequently fails to provide a sufficient number

of fixation points to secure small articular fragments. Clinical complications are inherently linked to the implant's intra-articular trajectory through the knee joint, which can elicit chronic patellofemoral pain. Furthermore, there is a recognized risk of septic arthritis, as well as synovial metallosis (the accumulation of metallic debris within the synovial fluid) secondary to the fretting or breakage of the interlocking screws.[25]

Distal Femoral Replacement (DFR)

In specific patient populations, attempts at internal osteosynthesis (utilizing plates or nails) are highly prone to failure due to poor bone quality or severe comminution. In such instances, primary endoprosthetic replacement is advocated as a „salvage procedure ". The principal advantage of this modality is the facilitation of immediate mobilization.[26, 27] Frequently, however, standard primary prostheses are inadequate due to significant bone stock depletion. Consequently, hinged or highly constrained knee systems are utilized, which compensate for ligamentous insufficiency and replace the deficient distal femoral segment.[28] Although this approach allows for immediate rehabilitation and circumvents fracture union-related complications, the procedure carries substantial risks. Given the magnitude of the surgical intervention and the advanced age of the typical patient demographic, the risk of perioperative complications (e.g., deep vein thrombosis, pulmonary embolism, and infection) is considerable. Furthermore, current literature documents a higher one-year mortality rate following this procedure when compared to elective arthroplasty.[16]

Risk factors for fixation failure and indications for augmentation

The management of distal femoral fractures remains a significant clinical challenge. The etiology of construct failure is multifactorial, most frequently arising from an imbalance between mechanical loading and the biological healing capacity of the host. Risk factors can be broadly categorized into three primary domains: patient-related, injury-related, and implant-related factors.

Patient-related factors (demographic and systemic variables)

Zlowodzki et al. (2006) discussed these factors as fundamental determinants of the "biological milieu" and the host's overall capacity for osseous regeneration, specifically highlighting advanced age and compromised bone density. Low bone mineral density (osteoporosis) represents a primary etiology for screw pull-out failure. In the presence of severe osteoporosis, locking screws-despite providing inherent fixed-angle stability-can migrate as a monolithic block through the soft cancellous bone (en bloc displacement). [29, 30]

Obesity represents an additional, critical patient-related risk factor. According to a 2014 study by Rodriguez et al., a body mass index (BMI) greater than 30 is a significant predictor for nonunion, which may dictate the need for proactive construct augmentation in this patient cohort. [19] Sainio et al. also identified body mass index (BMI) as the most significant prognostic variable for patient recovery.[32]

Although less frequently discussed as an isolated entity, metabolic syndrome (MetS) exerts a direct influence on bone metabolism. Numerous studies have demonstrated a correlation between MetS and decreased bone mineral density, alongside an elevated susceptibility to fragility fractures. According to Bonsu et al., this condition should be

regarded as a high-risk factor that necessitates a tailored postoperative management plan and a more aggressive optimization strategy.[33] Corroborating these findings, R. Dimitrova and K. Hristozov demonstrated that in non-diabetic postmenopausal women, low fasting levels of the hormone insulin (below 6.15 μ"IU/ml") signal a higher 10-year risk of osteoporotic fractures. For orthopedists, this hormonal marker identifies patients with severely impaired bone remodeling and a poor biological potential for healing.[34] Evaluating these metabolic parameters allows the orthopaedic surgeon to identify high-risk patients who may benefit from proactive dual-column stabilization to prevent secondary displacement and subsequent nonunion.

Injury-related factors (biomechanical and morphological)

Complex, multi-fragmentary fractures (AO Type C) carry a higher risk of instability. Rodriguez et al. highlighted that fracture geometry significantly influences construct stability, noting that highly comminuted, complete articular patterns (AO Type C) are particularly unstable. In these scenarios, the absence of medial cortical support forces the lateral locked plate to bear the load via a cantilever effect, which intensifies mechanical stress at the fracture site and ultimately drives hardware failure. Furthermore, in the context of periprosthetic fractures, the presence of an endoprosthesis alters the mechanical stress distribution and severely restricts the number and trajectory of the distal locking screws.

The compromised soft-tissue coverage in open fractures directly correlates with a higher risk of infection and fragment devascularization. According to Rodriguez et al., this serves as a significant predictor for impaired bone healing. Because open fractures damage surrounding soft tissues and cut off the blood supply to the bone during the initial trauma, they compromise its biological healing potential, leading to a significantly higher risk of nonunion ($P < 0.01$). This deficit impairs the body's natural capacity to self-repair, especially in severe, complex injuries (AO/OTA Type C).[19] The development of a postoperative infection constitutes a critical biological barrier to fracture healing, frequently resulting in construct loosening.

Implant and construct-related factors

According to Lujan et al., 2010, suboptimal plate length or excessive screw density-resulting in a restricted "working length"-render the construct overly rigid, thereby inhibiting physiological callus formation. Optimizing the "working length"-defined as the distance between the two screws nearest to the fracture site-is crucial. By leaving screw holes adjacent to the fracture line unoccupied, the overall flexibility of the plate is increased. A greater working length reduces construct stiffness, thereby increasing interfragmentary strain and providing the mechanical stimulus necessary for callus induction. Biomechanical simulations indicate that expanding the plate's working length by omitting adjacent screws yields a profound reduction in hardware stress, with optimization rates reaching up to 78% for screws when multiple holes are left vacant.[17] The second component is the screw density. The use of a reduced number of screws (typically three per fracture fragment) diminishes the overall construct stiffness.[34] High screw density renders the construct excessively rigid.[35] The third factor involves the choice of material (Titanium vs. Stainless Steel). Titanium alloys possess a Young's modulus (elastic modulus) of approximately 110 GPa, which is significantly closer to that of cortical bone compared to stainless steel (~200 GPa). Consequently, titanium plates are more elastic, which effectively mitigates the "stress shielding" effect.[19, 36] The

fourth component is Far Cortical Locking (FCL). This represents a contemporary fixation technique utilizing specialized screws that engage only the far cortex. This construct allows for controlled, elastic plate deformation, providing "parallel" micromotion that promotes the formation of symmetric callus across the fracture site.[37]

The final element is plate positioning(standoff) and length.

Maintaining a small gap (1-2 mm) between the plate and the bone-termed "standoff"-prevents direct contact pressure and alters mechanical stress distribution, effectively increasing construct elasticity. [34, 38] Furthermore, Ricci et al. emphasize the importance of implant dimensions, stating, "Use of relatively long plates is a technical factor that can reduce risk for fixation failure.

Indications for augmentation

The decision for supplementary medial stabilization is based on two critical pillars: the patient's biological capacity and the fracture morphology.

Biological Indications

Systemic Osteoporosis, Advanced Age, High BMI, and Metabolic Syndrome. In geriatric patients, especially when further complicated by a high BMI and metabolic syndrome, the primary clinical challenge shifts from the structural integrity of the implant to its "purchase" (anchorage) within the compromised, porous bone. Augmentation is therefore indicated to distribute the elevated mechanical load across a wider osseous surface area. [19, 31, 39]

Fracture morphology

Rajasekaran et al. identified a "critical medial defect" as the primary indication for dual-column stabilization. The objective is to restore the mechanical integrity of the medial column and prevent varus collapse. They developed a clinical-anatomical algorithm based on four factors: adequacy of the distal femoral bone stock, the extent of the medial void, fracture alignment, and fixation stability. [13]

1. Distal femoral bone stock. To evaluate the feasibility of stable distal fixation, the authors radiologically assessed the bone stock within a 3-cm metaphyseal zone proximally from the joint line. This area was demarcated on the AP view by a perpendicular line from the intercondylar notch and on the lateral view from the center of the condyles. Cases with suspected bone loss or poor quality within this region were categorized as inadequate.
2. Extent of the medial void. The medial bone defect (void) of the distal femur was quantified intraoperatively following anatomical alignment correction. It was defined as the distance (in centimeters) between the distal medial cortex of the intact proximal fragment and the proximal medial cortex of the intact distal fragment. Crucially, this assessment must be performed intraoperatively only after proper fracture reduction has been achieved.

3. Alignment of the fracture. Fracture alignment was radiologically evaluated on full-length AP femoral radiographs using the mechanical lateral distal femoral angle (mLDFA) , defined as the angle between the femoral mechanical axis and the joint line of the condyles. An mLDFA of 87° ± 2° was established as the threshold for acceptable alignment. Deviations from this target range were categorized as varus (increased angle) or valgus (decreased angle).
4. Stability of the fixation. In the formulated algorithm, stable fixation was defined as a lateral locking plate with an optimized working length (three times the fracture zone for comminuted fractures and eight times for transverse fractures), showing no evidence of mechanical failure or implant cut-out. [40] In cases of compromised distal bone stock, management is age-dependent: patients over 65 years are directed to total joint arthroplasty, whereas for those under 65 years, fixation reinforced with structural fibular allograft struts is performed. When the bone stock is adequate but mechanical failure with malalignment is present, revision osteosynthesis is executed, followed by intraoperative measurement of the residual medial void. Finally, cortical defects under 2 cm are addressed with metaphyseal fibular struts, while gaps exceeding 2 cm require the authors recommended dual-column stabilization via supplemental medial plating, combined in both scenarios with cancellous autografting.

3. Methods for augmentation

Cement augmentation (Polymethyl Methacrylate-PMMA)

The primary objective of PMMA augmentation is not to "bond" the bone, but to modify the screw-bone interface. In this technique, the cement is injected in a liquid state, either through cannulated screws or directly into the bone channels. It permeates the cancellous bone, filling the voids and creating a larger volume of mechanical purchase (macro-interlocking). Indications for this application include severe osteoporosis (low T-score), periprosthetic fractures (where stability is critical), revision surgery (when previous screw channels are compromised), and AO/OTA Type 33-C fractures in elderly patients at risk for early weight-bearing. Wähnert et al. demonstrated the efficacy of this method, establishing that augmentation significantly enhances the mechanical resistance of the fixation under cyclic loading compared to non-augmented constructs ($P = 0.011$). Survival analysis confirmed the statistically significant superiority of the augmented group ($P = 0.007$), with bone mineral density (BMD) serving as a significant covariate for the final outcome ($P = 0.014$). [41] Similarly, Jazrawi et al. (2000) advocated for the application of this technique specifically for severely comminuted distal femoral fractures and osteopenic bone with poor screw purchase, offering a simple alternative for enhancing fixation stability while mitigating complications associated with standard fixation.[42] The primary advantage of PMMA augmentation is the significantly increased pull-out strength; studies indicate that augmenting as few as two distal screws can enhance construct stability by over 60% compared to standard fixation. The cement prevents micromotion of the screw head within the soft cancellous bone, which is the leading cause of reduction loss and varus collapse.[43] Conversely, the method carries inherent risks. The exothermic reaction

during cement polymerization can generate temperatures exceeding 50°C, potentially resulting in osteocyte necrosis and vascular injury, which may paradoxically lead to long-term periprosthetic bone resorption. Furthermore, in the event of revision surgery (e.g., due to infection), the removal of cemented screws is exceptionally challenging and often results in significant bone stock loss. Biomechanically, excessive cement augmentation can render the construct overly rigid, potentially suppressing biological healing. This method cannot compensate for suboptimal fracture reduction: if the anatomical axis (valgus/varus) is not restored, cement will not prevent construct failure. Finally, in intra-articular fractures, there is a risk of intra-articular cement extravasation, which may induce chemical arthritis, cartilage degeneration, or a "foreign body" inflammatory reaction.

Additional medial plating

The indications for double fixation in the distal femur can be broadly divided into the following categories: double plating for native fractures, periprosthetic fractures, nonunion or malunions.

Double plating for native distal femoral fractures

The current literature on double plating for distal femoral fractures predominantly consists of retrospective or prospective case series, whereas comparative controlled trials against single plating remain limited. While diverse surgical approaches have been reported, the standard construct typically involves a supplementary medial plate alongside the primary lateral fixation.[44] In a biomechanical study, Park et al. (2019) demonstrated that supplementary medial fixation increases significantly the construct stability. Fontenot et al., tested a type 33-C fracture model. They reported a 70% increase in axial stiffness when a medial reconstruction plate was added. Double plating completely prevented plate bending at the fracture gap. Furthermore, it increased load capacity by up to 29.2% (5522 N vs. 4273.2 N) and significantly reduced ultimate fracture displacement compared to single-side lateral locking configurations. [45, 46, 47] These findings are supported by the research of Todorov et al., who evaluated patients with osteoporotic bone. The addition of a second plate significantly reduced the stress on the lateral implant (e.g., LISS - Less Invasive Stabilization System), thereby minimizing the risk of metal fatigue and subsequent implant failure. [48, 49]

The concept of dual-column stabilization using an additional medial plate for distal femur fractures was first described by Sanders et al. in 1991. The authors applied an additional medial plate in 9 distal femoral fractures with compromised medial cortical support. They concluded that medial cortical comminution, a short distal condylar fragment, and loss of metaphyseal bone were clear indications for double plating.[50] In 1994, Chapman et al. recommended augmentation with a second plate for AO Type C3 fracture patterns, specifically those with medial condyle “Hoffa” fragments, very distal transcondylar supracondylar femoral fractures, and supracondylar/intercondylar fractures with extensive medial metaphyseal comminution or bone loss. Low horizontal transcondylar fractures associated with an intercondylar split were also considered for this technique. [51] Ziran et al. (2002) included Gustilo-Anderson open fractures (including severe Grades IIIA, IIIB, and IIIC) as indicated for double plate fixation, demonstrating favorable clinical outcomes and reliable bone healing in the majority of patients. [52] Dugan et al. used double plating for open supracondylar femoral fractures with large bone defect. In this series of 15 patients, double plating achieved a 100%

bone healing rate and effectively maintained anatomical alignment with zero deep infections. Postoperative knee stiffness, however, was noted as a common complication. [53]

Bai et al. used an intraoperative varus stress test as an indication for double plating. They applied a manual varus load to the knee joint to evaluate structural stability. A positive test result-indicated by persistent instability or displacement after lateral plating-lead to the application of a medial plate. The study evaluated a total of 58 patients representing 60 cases of distal femoral fractures. There was no significant difference in the average operation time, intraoperative hemorrhage, fracture healing time and excellent and good rates of postoperative knee function between two groups.[54]

Double plating for distal femoral nonunion and malunion

While representing a low incidence (4–6% of all femoral fractures), distal femoral fractures demonstrate a high rate of nonunion following surgery (up to 20%), mainly resulting from metaphyseal comminution, poor bone quality, or suboptimal fixation stability. [3] Holzman et al. (2016) evaluated a cohort of 23 patients with nonunion treated by adding a medial locking plate and autogenous bone graft. Depending on the condition of the initial hardware, the original lateral plate was either left in situ or replaced with a new one in instances of construct failure or septic nonunion. Utilizing this specific treatment algorithm, they reported a 95.2% radiographic consolidation rate within a 12-month period.[55] Rajasekaran et al. suggested that an auxiliary medial plate combined with bone grafting was indicated for medial defects greater than 2 cm. Out of the 62 patients managed with this protocol, six underwent additional medial plating and bone grafting. Among them, two patients achieved union within 6 months, while four reached consolidation at 7 months. The final knee range of motion ranged from 105° to 110°. [13]

Double plating for periprosthetic distal femoral fractures

Management of periprosthetic distal femur fractures requires highly stable fixation to prevent mechanical failure. Stable fixation in periprosthetic fractures is frequently compromised by several adverse factors, including localized osteoporosis, impaired vascularity around the knee joint, and the occlusion of fracture lines by the prosthesis. The latter significantly impedes accurate anatomical reduction due to the absence of clear landmarks. Additionally, the supracondylar region is biomechanically vulnerable, as the femoral component of a total knee arthroplasty (TKA) weakens the adjacent bone stock. To counteract these issues, a double-plate construct can effectively immobilize the fracture fragments, offering sufficient rigid fixation to support bone healing. Cicek et al. evaluated 22 osteoporotic patients with Su Type III periprosthetic distal femur fractures after TKA Dual plating successfully resisted varus stress, maintaining physiological alignment with zero varus deformities. Consequently, 91% of patients (n = 20) achieved radiographic union, reaching pain-free weight-bearing at a mean of 4.9 ± 1.1 months. Two cases (9.1%) necessitated revision due to nonunion and displacement. [56] Furthermore, Kriechling et al. (2024) analyzed clinical cases of periprosthetic fractures fixed with dual plating. In these instances, the presence of a total knee arthroplasty (TKA) severely compromises the available space for fixation, forcing the use of shorter and fewer screws in the distal block. The authors concluded that dual-column stabilization provides the necessary torsional stability to allow for early weight-bearing in elderly patients without risking fixation failure. [27, 57]

In a meta-analysis of 14 studies Prince et al. reported a rapid reduction in distal femoral bone mineral density after TKA, with the greatest decrease occurring during the first 6 months and persisting for up to 24 months. This finding may be relevant to fixation planning in early periprosthetic fractures but does not independently establish an indication for supplementary medial plating.[58] Beeres et al. fixed 5 periprosthetic fractures by minimally invasive double-plate osteosynthesis. They used a medial helical shaped plate. No implant failure or loss of reduction was seen after postoperative unrestricted weight bearing. [59]

Other double plating constructs

Alternative double-fixation strategies include the dual-plate construct described by Bergin et al., who combined intraosseous and lateral extraosseous plating for ten complex fractures with severe bone loss or nonunion (including seven distal femur fractures). While 80% (n = 8) of these fractures healed uneventfully after the index procedure, two cases (20%) necessitated a single additional operation each to secure complete union. [60]

Concerns when adding a medial plate.

Major concern is the soft tissue and vessel stripping, which may induce a higher risk of infection. [61] Cadaveric study performed by Rollick et al. (2020) does not support this concern. The authors demonstrated that the additional placement of a medial plate does not result in clinically significant devascularization of the distal femur. An additional medial plate incurred only a minor 4.2% decrease in arterial contribution to the extremities. [62] However, postoperative knee stiffness was observed in 21.2% of cases, which can significantly interfere with physical therapy. The amount of soft-tissue stripping can be limited with more minimally invasive procedures to avoid excessive scar formation and knee stiffness.[52] In a cadaveric study, Jiamton et al. demonstrated the safety of performing the MIPO (Minimally Invasive Plate Osteosynthesis) technique along the medial aspect of the femur. Although the addition of a second (medial) plate provides mechanical stability and prevents varus collapse in high-energy or comminuted fractures, concerns exist in the literature regarding the excessive construct stiffness. [63, 64] This excessive construct rigidity is directly linked to screw density. Consequently, the use of a reduced number of screws-typically three per fracture fragment-is recommended to diminish the overall construct stiffness and optimize the mechanical environment for bone healing. [34, 45, 46]

Nail-plate combination

Compared to dual-column stabilization (double plating), the combination of an intramedullary nail and a plate inflicts less soft-tissue trauma and results in reduced blood loss, thereby lowering the risk of infection and improving patient outcomes. This approach achieves balance between construct stability and physiological micromotion, which promotes fracture healing and facilitates early functional recovery.[65] Liporace et al. hypothesized that a retrograde intramedullary nail (rIMN) aligns closely with the anatomical axis of the femur allowing for favorable load distribution, as the stress is effectively transferred through the nail.[66] Consequently, this increases the likelihood of accelerated bone union and enables early mobilization and the resumption of activities

of daily living.[67] According to Başcı et al., for AO Type 33-A3 fractures, this combination demonstrates greater resistance to displacement under both torsional and axial loading compared to isolated lateral plating or isolated nailing.[68] The nail-plate combination is particularly advantageous in periprosthetic fractures characterized by poor bone quality. Kanabur et al. advocate for the use of a statically locked rIMN in conjunction with a maximum-length lateral locking plate for periprosthetic fractures in patients with osteopenia or obesity. [69] However, this method is strictly applicable only if the knee arthroplasty component is of the "open box" design, which allows for the passage of the nail through the intercondylar notch. If significant articular comminution is present, nail insertion may be challenging or entirely contraindicated; in such cases, dual-plating stabilization remains the superior therapeutic option.

Biological augmentation (Strut allograft)

Chee et al. described a combined technique utilizing an intramedullary fibular strut allograft as an "internal splint" in conjunction with dual locking plates for complex AO/OTA 33-C fractures. The authors emphasize the dual benefit of this method: providing robust mechanical support while simultaneously stimulating biological fracture healing. [70] This construct achieves a favorable biomechanical effect, where the bone graft bears axial loads while the plates ensure rotational stability. Due to the high construct stiffness and structural integrity, patients can initiate full weight-bearing shortly after surgery with a reduced risk of mechanical failure. [27,70] Beyond mechanical support, the allograft accelerates biological union by acting as a structural scaffold that gradually undergoes incorporation and remodeling into host bone. [71] This method successfully addresses the challenges associated with significant bone loss, providing both biological stimulation and the potential for early rehabilitation.[70] Ibrahim et al. also reported favorable outcomes in 30 elderly patients with AO/OTA 33-A3, 33-C2, and 33-C3 fractures. The mean patient age was 75.3 years. Healing time ranged from 16 to 23 weeks, with a mean of 18.4 weeks, and no instances of nonunion were observed.[72]

Limitations and Complications

The primary disadvantages and risks associated with this method relate to potential immunological response. Although the risk is minimal given the rigorous processing protocols of modern bone banks, the transmission of infectious agents (e.g., hepatitis, HIV, prions) remains a theoretical concern. As this is allogenic tissue, the host may elicit an immunological response, which can delay graft incorporation or lead to rejection. Furthermore, there are significant technical and surgical challenges. The procedure is associated with increased operative time and complexity. Shaping the cortical allograft to match the anatomical curvature of the femur is often demanding and significantly prolongs surgery. The application of cortical allografts is accompanied by significant logistical and financial challenges, stemming from the high cost of these biological products and their procurement. Furthermore, the limited availability of specialized bone banks capable of providing fibular or femoral allografts with appropriate anatomical dimensions hinders their widespread implementation and restricts the feasibility of their timely use in daily clinical practice. [70, 71]

4. Discussion

Distal femur fractures remain challenging. Comminution and bone loss are usually problematic in higher energy fractures, while bone quality and early mobilization determine the outcome in the elderly patients. In these cases, isolated lateral plating often proves insufficient, thereby necessitating addition of a medial plate.

Several biomechanical investigations have demonstrated that double plating provides higher stability compared to single-plate osteosynthesis. [20, 29, 36, 38, 73] Medial column support neutralizes the cantilever effect by restoring and preventing the varus collapse observed as a complication in single lateral plate fixation. [19] Overall construct rigidity is increased, sharing the mechanical load and protecting the primary implant from metal fatigue and breakage. [20] In geriatric patients with compromised bone quality, this strategy optimizes the purchase of fixation elements within the osteoporotic cancellous bone, preventing their migration or cut-out. [40] The stable construct achieved through the use of an additional medial plate or a nail-plate combination permits immediate postoperative full weight-bearing, which is critical for early mobilization, the avoidance of systemic complications associated with prolonged recumbency, and a swift return to both daily activities and the workforce. [27]

In the geriatric population, the prognosis following distal femoral fractures remains poor, with data indicating that one-year mortality rates among elderly patients undergoing surgical intervention range from 13.4% to 35%.[3] Age-related comorbidities-such as osteoporosis, obesity, lead to an increase in the incidence of these fractures. [74] This trend is driven not only by the general aging of the population but also by the fact that modern elderly patients often maintain a high level of physical activity. [39] The use of a single lateral plate alone is associated with an increased incidence of nonunion (pseudoarthrosis) and mechanical construct failure. [12]

The main disadvantages of supplemental augmentation-regardless of whether dual plating, a nail-and-plate combination, biological allograft, or cement is used-include a significant increase in the overall stiffness of the fixation. Also, the surgical implementation of a secondary construct inherently prolongs operative time, increases intraoperative blood loss, leads to additional soft-tissue injury, and disrupts the periosteum. [51, 65, 68, 70] Last but not least, the higher cost of placing an additional implant and performing cement augmentation must be noted, and when it comes to a bone graft (allograft)-in addition to the higher cost-the limited access to a bone bank in many medical facilities, the complex logistics around their transport, and the need for technological waiting time are added.

The technique of augmentation has evolved over the years, to address the aforementioned shortcomings. To limit the blood loss and tissue damage, authors have implemented less invasive approaches for reduction and plate application. [64] The industry is working to provide a dedicated medial plate. Its design is based on software tools for in-depth bone density analysis, which have the potential to enhance implant-to-femur fit, making application easier and faster. [75] However, long-term clinical data regarding the real-world outcomes remain to be established. [76]

5. Conclusions

In conclusion, distal femoral fractures should receive the same standard of care as the rest of the femoral fractures. Fast track surgery should be the accepted norm.

Augmented fixation makes early rehabilitation safer. The cost in complexity and soft tissue damage probably pays off in the long run.

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