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## Aims and Scope

*The Journal of Musculoskeletal Trauma* is the official publication of the Korean Orthopaedic Trauma Association. It is an international, peer-reviewed, open access journal dedicated to advancing the science, education, and clinical care of musculoskeletal trauma. The journal provides a platform for the dissemination of high-quality research, innovative techniques, and multidisciplinary approaches that improve patient outcomes in the field of orthopedic trauma and related disciplines.

As an open access journal, all articles are freely available to readers worldwide, ensuring the widest possible dissemination of knowledge and promoting collaboration among researchers, clinicians, and educators.

The scope of the journal encompasses the prevention, diagnosis, treatment, and rehabilitation of musculoskeletal injuries, including but not limited to:

- Fractures, dislocations, and soft tissue injuries of the extremities and axial skeleton
- Advances in surgical techniques, implants, and prosthetic devices
- Biomechanical and biological research related to trauma and tissue healing
- Rehabilitation strategies and innovations for functional recovery
- Clinical and translational research bridging basic science and clinical practice

The journal invites submissions of original research articles, systematic reviews, meta-analyses, technical notes, and correspondence that contribute to the advancement of musculoskeletal trauma care. Submissions are welcomed from all regions of the world, promoting a diverse and inclusive exchange of knowledge and perspectives.

The *Journal of Musculoskeletal Trauma* serves as a resource for orthopedic surgeons, trauma specialists, researchers, rehabilitation professionals, and all healthcare providers involved in the care of musculoskeletal injuries. By fostering collaboration and disseminating cutting-edge findings, the journal aims to elevate the standards of trauma care globally.

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# Minimally invasive plate osteosynthesis of the clavicle and humerus: indications, surgical techniques, and clinical outcomes

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Minimally invasive plate osteosynthesis (MIPO) is an established strategy for lower-extremity fractures because it preserves periosteal vascularity, maintains fracture hematoma, and promotes secondary bone healing through relative stability. Its use has expanded to fractures around the shoulder girdle, including fractures of the clavicle, proximal humerus, humeral shaft, and distal humerus. However, adoption in the upper extremity has been more cautious because of complex regional anatomy, narrow soft-tissue corridors, and the proximity of major neurovascular structures. This review summarizes current evidence on the indications, surgical techniques, clinical outcomes, and complications of MIPO for clavicle and humerus fractures. For clavicle fractures, MIPO is most commonly indicated for displaced multifragmentary midshaft fractures and provides union rates and functional outcomes comparable to those of conventional open reduction and internal fixation, with potential advantages in soft-tissue preservation and cosmesis. In proximal humerus fractures, MIPO performed through a deltoid-splitting approach has yielded favorable outcomes in selected two- and three-part fractures, whereas four-part fractures have less predictable outcomes and higher complication rates. In humeral shaft fractures, anterior MIPO provides stable fixation without routine radial nerve exploration and has shown reliable union with fewer complications in selected fracture patterns. For extra-articular distal humerus fractures, minimally invasive anterior and posterior plating techniques, including the use of an inverted proximal humeral internal locking system plate, have shown favorable clinical and radiographic outcomes despite technical challenges related to limited distal fixation. Overall, MIPO can achieve high union rates and satisfactory functional outcomes in clavicular and humeral fractures when indications are appropriate, safe anatomical corridors are respected, and surgical technique is meticulous.
**Level of evidence:** Not applicable.

**Keywords:** Minimally invasive surgical procedures; Clavicle; Humeral fractures

## Introduction

Open reduction and internal fixation (ORIF) remains one of the most commonly utilized surgical strategies for fracture management. Despite its widespread use, this technique is associated with several well-recognized complications, including deep infection, nonunion, implant failure, and refracture following implant removal [1-3]. These adverse outcomes are thought to be partly attributable to extensive periosteal stripping and soft-tissue disruption at the fracture site, which may compromise the biological environment necessary for fracture healing [4]. Minimally invasive plate

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osteosynthesis (MIPO) has emerged as an alternative fixation strategy founded on the principles of indirect reduction and bridge plating without direct exposure of the fracture site. By preserving periosteal blood supply and maintaining fracture hematoma, MIPO supports a biologically favorable environment that facilitates secondary bone healing through relative stability [5]. However, MIPO also presents several technical limitations. Because the fracture site is not directly visualized, the accuracy of reduction depends substantially on surgical experience and fluoroscopic interpretation. Furthermore, the technique carries an inherent risk of neurovascular injury and typically requires increased intraoperative fluoroscopic guidance [6].

MIPO has become well established in the management of lower-extremity fractures, with numerous studies demonstrating favorable clinical and radiographic outcomes [7-9]. These advantages have largely been attributed to preservation of periosteal blood supply, maintenance of fracture hematoma, and promotion of secondary bone healing through relative stability. More recently, the application of MIPO has expanded to fractures around the shoulder girdle, including the clavicle, proximal humerus, humeral shaft, and distal humerus, with an increasing number of studies reporting satisfactory union rates and functional outcomes when appropriate indications and meticulous surgical techniques are employed [6,10,11]. However, adoption of MIPO in the upper extremity has progressed more cautiously than in the lower extremity. This is primarily related to the complex regional anatomy, the close proximity of critical neurovascular structures such as the axillary and radial nerves, and the limited safe corridors available for implant insertion. In addition, indirect reduction techniques in the upper extremity are often technically demanding because restoration of alignment, length, and rotational profile must be achieved without direct visualization of the fracture site. These technical challenges are further compounded by region-specific biomechanical considerations, including cantilever forces in the clavicle, varus collapse in the proximal humerus, torsional stress in the humeral shaft, and limited distal fixation in the distal humerus, which necessitate distinct fixation strategies.

Given these anatomical, biomechanical, and technical considerations, the indications, surgical strategies, and potential complications associated with MIPO vary substantially according to the involved anatomical region. Accordingly, comprehensive understanding of both the shared biological principles and the region-specific technical challenges of MIPO around the shoulder is essential for optimizing clinical outcomes. Although several previous reviews have addressed MIPO techniques for specific fracture locations, a comprehensive review integrating region-specific indications, anatomical considerations, surgical techniques, and clinical outcomes across the clavicle and humerus remains limited. Therefore, this review aims not only to summarize the current evidence regarding MIPO for clavicle and humerus fractures, but also to provide a practical framework for orthopedic trauma surgeons by emphasizing region-specific indications, surgical strategies, clinical outcomes, potential complications, and safe anatomical corridors associated with each anatomical region. A summary of the key indications, surgical approaches, neurovascular structures at risk, fixation strategies, and major complications for each anatomical region is provided in Table 1. This narrative review was based on a literature search of PubMed and Google Scholar databases. Studies addressing the indications, surgical techniques, clinical outcomes, and complications of MIPO for clavicle and humeral fractures were reviewed, with emphasis on clinically relevant studies, comparative investigations, and representative technical reports published in English.

### Ethics statement

Written informed consent was obtained from the patients for publication of their images in this review.

## Clavicle fracture

MIPO for clavicle fractures is primarily indicated for displaced multifragmentary midshaft fractures in which anatomical reduction of each intermediate fragment is not essential for restoration of satisfactory functional alignment. In these fracture patterns, the principles of bridge plating and biologic fixation permit maintenance of fracture fragment vascularity while preserving overall clavicular length and alignment. Selected simple midshaft fractures may also be considered for MIPO, particularly in the presence of substantial soft-tissue compromise or when extensive surgical exposure is undesirable. However, in simple fracture configurations with minimal soft-tissue injury, where


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**Table 1.** Key considerations for MIPO according to anatomical region

| Region | Main indication | Surgical approach | Neurovascular structure at risk | Fixation strategy | Major complications |
|---|---|---|---|---|---|
| Clavicle | Multifragmentary midshaft fracture | Anteroinferior or superior MIPO | Subclavian vessels, brachial plexus | Bridge plating | Hypoesthesia, implant irritation, refracture |
| Proximal humerus | Displaced 2-part and selected 3-part fractures | Deltoid-splitting approach | Axillary nerve | Locking plate fixation | Varus collapse, screw penetration, shoulder stiffness |
| Humeral shaft | Long oblique, spiral, comminuted, segmental fractures | Anterior MIPO | Radial nerve, musculocutaneous nerve | Bridge plating | Malreduction, nonunion |
| Extra-articular distal humerus | Distal-third diaphyseal fractures | Anterior MIPO, posterior MIPO, inverted PHILOS | Radial nerve | Distal fixation with locking screws | Implant irritation, fixation failure, nerve injury |

MIPO, minimally invasive plate osteosynthesis; PHILOS, proximal humeral internal locking system.

direct anatomical reduction can be reliably achieved, conventional ORIF generally remains the preferred treatment strategy. Accordingly, the advantages of MIPO are considered most pronounced in multifragmentary midshaft clavicle fractures rather than in simple fracture patterns [12].

To achieve adequate construct stability, fixation should include at least three screws within both the medial and lateral main fragments. By utilizing two limited incisions and indirect reduction techniques, MIPO preserves periosteal blood supply and surrounding soft-tissue attachments while minimizing surgical dissection. Biomechanical studies comparing superior and anteroinferior plating have reported results that vary with the loading mode, with greater bending rigidity observed for anteroinferior plating [13,14]. Nevertheless, clinical studies have reported comparable union rates and functional outcomes between the two fixation strategies [15-17]. Anteroinferior plating may provide advantages related to reduced implant prominence and decreased soft-tissue irritation [15]. In multifragmentary clavicular fractures associated with segmental bone defects, anteroinferior plating may be preferable because the cantilever effect generated by superior plating constructs can increase bending stress concentration at the fracture site [18]. A randomized clinical trial involving 37 patients with clavicle fractures compared superior and anteroinferior plating techniques and demonstrated no significant differences in clinical or radiographic outcomes between the two plate positions. Both techniques achieved satisfactory fracture union and functional recovery, with no significant difference in complications between the groups (one plate failure and one nonunion in the superior plating group) [19]. In summary, the biomechanical differences between the two plate positions depend on the loading mode, and anteroinferior plating may reduce implant prominence and soft-tissue irritation. Therefore, plate position should be selected according to fracture morphology, soft-tissue condition, and surgeon preference, as both techniques have demonstrated comparable clinical outcomes.

### Surgical technique of the anteroinferior plating

The patient is positioned in the beach-chair position, and fluoroscopy is arranged to obtain anteroposterior and oblique cephalic and caudal tilt views. A lateral incision approximately 3 cm in length is created along the anterior border of the clavicle, and the deltoid-trapezius interval is carefully developed to expose the lateral clavicular segment. A submuscular tunnel is subsequently created toward the medial side using a periosteal elevator while carefully protecting the underlying neurovascular structures. The plate is inserted through the lateral window in a reversed orientation to allow passage across the fracture site and is then rotated into its anatomical position. A second medial incision is created over the medial portion of the plate, and blunt dissection is performed beneath the platysma and pectoralis major to facilitate definitive plate positioning (Fig. 1). Indirect fracture reduction is achieved using percutaneous joystick techniques with threaded Kirschner wires to correct vertical displacement and restore alignment. Temporary fixation is established using 2.8-mm drill bits placed at both ends of the plate, followed by insertion of cortical screws to restore anterior-posterior alignment. After satisfactory reduction and implant positioning are confirmed fluoroscopically, definitive fixation is completed using locking screws [11,20]. Following definitive fixation, meticulous soft-tissue

repair is performed to restore muscular continuity and ensure adequate implant coverage.

### Clinical outcomes

Sohn et al. [11,20] reported a clinical series of 19 patients with displaced midshaft clavicle fractures treated using the anteroinferior MIPO technique (Fig. 2). Radiographic union was achieved in all patients at a mean of approximately 15 weeks postoperatively. Clavicular length was successfully restored without clinically significant shortening, and shoulder range of motion was nearly symmetric to that of the contralateral extremity at final follow-up. No major complications were observed; however, one patient developed localized hypoesthesia, and another sustained a refracture adjacent to the plate following subsequent trauma [11,20]. A recent large-scale meta-analysis evaluating MIPO for clavicle midshaft fractures demonstrated outcomes comparable to those of ORIF with respect to time to union, functional outcomes, and complication rates [21]. However, MIPO demonstrated several additional advantages, including shorter operative time, lower rates of neurological impairment, and superior cosmetic outcomes [22,23].

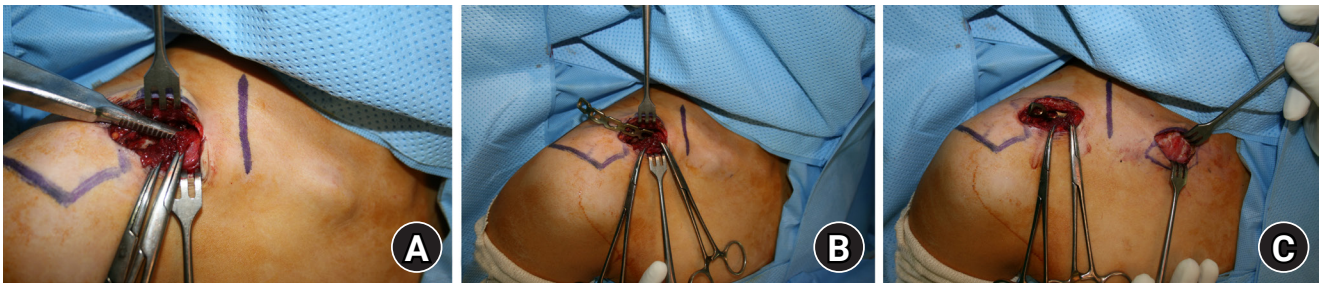



**Fig. 1.** (A) Lateral approach demonstrating development of the deltoid-trapezius interval and creation of a submuscular tunnel. (B) The plate is inserted through the lateral window in an inverted orientation and advanced across the fracture site. (C) The plate is rotated into its anatomical position, and a second medial incision is created to facilitate definitive plate positioning through blunt dissection beneath the platysma and pectoralis major muscles.

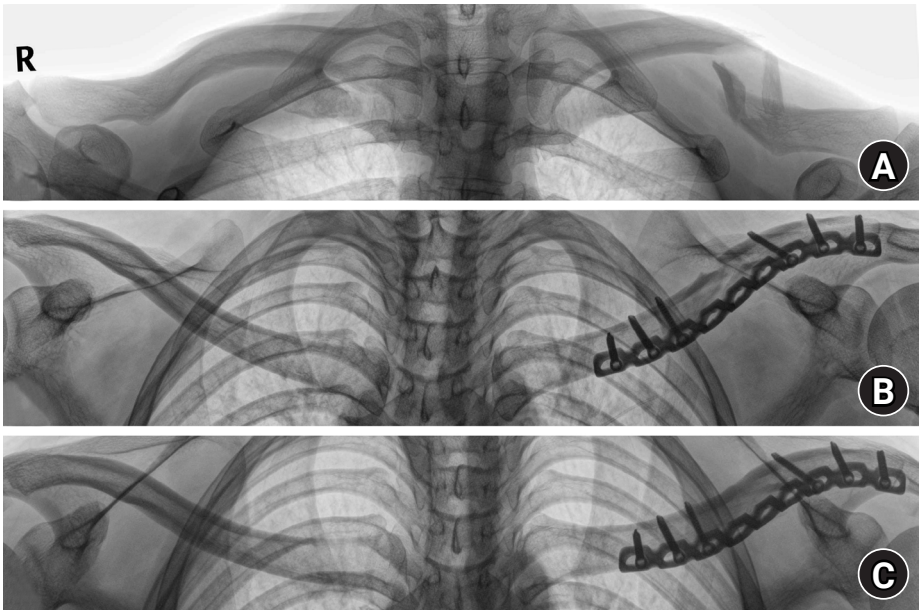



**Fig. 2.** A 43-year-old male patient with a fragmentary wedge-type (AO/OTA 15.2B3) midshaft clavicle fracture. (A) Preoperative radiograph showing a displaced fragmentary wedge fracture of the clavicle. (B) Immediate postoperative radiograph after minimally invasive plate osteosynthesis. (C) Radiograph obtained 13 months postoperatively showing solid bony union with maintained alignment and stable fixation without implant-related complications.


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## Proximal humerus fracture

MIPO for proximal humerus fractures is most commonly performed through a deltoid-splitting approach using indirect fracture reduction and locking plate fixation [24,25]. Favorable clinical and radiographic outcomes have been reported particularly in displaced two-part fractures and selected three-part fractures, whereas four-part fractures are associated with significantly inferior outcomes and substantially higher complication rates [26,27]. Consequently, the application of MIPO in complex fracture configurations, particularly four-part fractures, remains controversial because accurate reduction and stable fixation may be difficult to achieve using minimally invasive techniques alone. In such circumstances, conversion to an open approach should be considered when satisfactory reduction cannot be reliably obtained [26]. Fractures associated with substantial medial cortical or calcar comminution, as well as poor bone quality, also warrant careful consideration because inadequate medial column support is strongly associated with postoperative loss of reduction and screw cutout following locking plate fixation [26,28]. Therefore, careful patient selection and thorough assessment of fracture morphology, reducibility, bone quality, and medial column integrity are essential when considering MIPO for proximal humerus fractures [6,27]. In practical terms, ideal candidates for MIPO include displaced two-part fractures and selected three-part fractures in which satisfactory indirect reduction and stable fixation can be achieved. Conversely, four-part fractures, fractures with severe medial calcar comminution, poor bone quality, or irreducible fracture patterns should be approached with caution because these factors are associated with increased risks of loss of reduction and fixation failure. When adequate reduction cannot be reliably obtained through minimally invasive techniques, conversion to an open approach should be considered.

### Surgical technique

The patient is positioned supine with the affected arm draped free to allow intraoperative manipulation and fluoroscopic assessment. Compared with the beach-chair position, the supine position facilitates reduction by preventing posterior sagging of the arm. Closed reduction is initially attempted under fluoroscopic guidance using longitudinal traction combined with varus or valgus-directed correction, although varus correction is required in most cases. Restoration of the medial calcar and correction of varus deformity are essential before definitive fixation.

A proximal incision approximately 4–5 cm in length is created beginning distal to the anterolateral corner of the acromion. The deltoid muscle is split longitudinally along its anterior raphe without detachment. Because the axillary nerve typically crosses beneath the deltoid approximately 5–7 cm distal to the acromion, careful protection of the nerve is mandatory throughout the procedure. During preparation of the submuscular tunnel, the axillary nerve is palpated digitally while the index finger is maintained beneath the deltoid to guide safe passage of the plate and minimize the risk of iatrogenic injury (Fig. 3A).

When greater tuberosity fragmentation is present, nonabsorbable sutures placed at the rotator cuff-bone junction and temporary Kirschner wires may be used to facilitate reduction and provisional fixation (Fig. 3B). After creation of a subdeltoid extraperiosteal tunnel, the plate is inserted distally through the proximal window. Plate height should

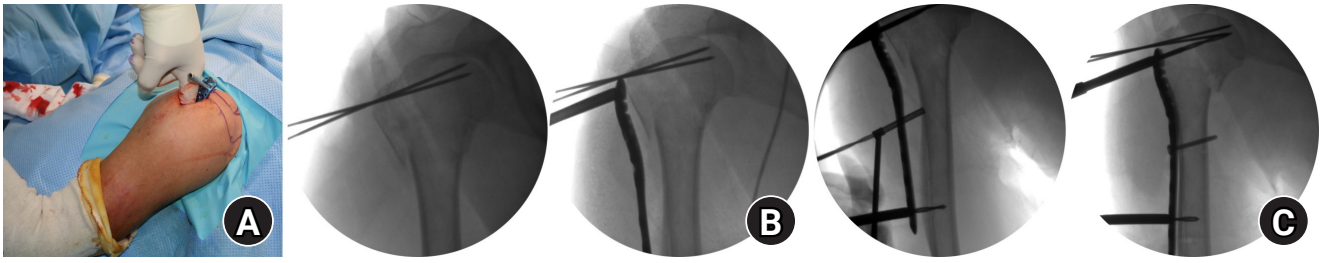



**Fig. 3.** (A) Digital palpation of the axillary nerve during preparation of the submuscular tunnel to prevent iatrogenic nerve injury. (B) Temporary fixation of the reduced greater tuberosity using Kirschner wires positioned to avoid interference with subsequent plate placement. (C) Indirect restoration of the neck-shaft angle and correction of varus-valgus alignment using a positional cortical screw inserted through the elongated combi-hole to draw the humeral shaft toward the plate.

be maintained approximately 5 mm inferior to the greater tuberosity to avoid subacromial impingement.

A distal incision is then created through the deltoid-biceps interval, preserving the cephalic vein whenever possible. The brachialis muscle is split longitudinally to expose the anterior humeral shaft. Reduction is achieved indirectly using a positional cortical screw inserted through the elongated combi-hole, which draws the shaft toward the plate and restores the neck-shaft angle and coronal alignment (Fig. 3C). Rotational alignment and plate position are subsequently confirmed fluoroscopically, including axillary views obtained with gentle shoulder abduction and external rotation.

Once satisfactory reduction has been achieved, proximal locking screws are inserted in a divergent configuration, followed by additional distal fixation. In fractures with medial metaphyseal comminution or poor bone quality, inferomedial calcar screws or fibular strut graft augmentation may be added to improve medial column support and reduce the risk of secondary varus collapse. Shoulder abduction to approximately 90° facilitates insertion of inferomedial screws while reducing tension on the axillary nerve.

Final fluoroscopic assessment should confirm restoration of overall alignment, appropriate plate position, and satisfactory screw length in multiple planes. Early passive and active range-of-motion exercises are initiated postoperatively as tolerated.

## Clinical outcomes

Sohn and Shin [26] evaluated 62 patients with proximal humerus fractures treated using the MIPO technique, including 27 two-part, 24 three-part, and 11 four-part fractures (Fig. 4). Patients with four-part fractures demonstrated significantly lower Constant scores than patients with three-part fractures and significantly decreased neck-shaft angles at final follow-up compared with patients with two- and three-part fractures. Furthermore, the overall complication rate was significantly higher in the four-part fracture group and included postoperative shoulder stiffness as well as radiographic complications such as plate impingement, screw penetration, varus collapse, and malreduction. In another clinical study involving 34 patients with proximal humerus fractures treated using MIPO, radiographic union was achieved in all patients, with satisfactory functional outcomes and no major complications [29]. A meta-analysis including 11 studies comparing ORIF and MIPO for proximal humerus fractures demonstrated no significant differences between the two techniques with respect to Constant scores, radiographic outcomes, and complication rates; however, operative time was significantly shorter in the MIPO group [30]. Collectively, these findings suggest that satisfactory radiographic and functional outcomes, including reliable fracture union and restoration of proximal humeral alignment, can be achieved using MIPO in appropriately selected displaced proximal humerus fractures.

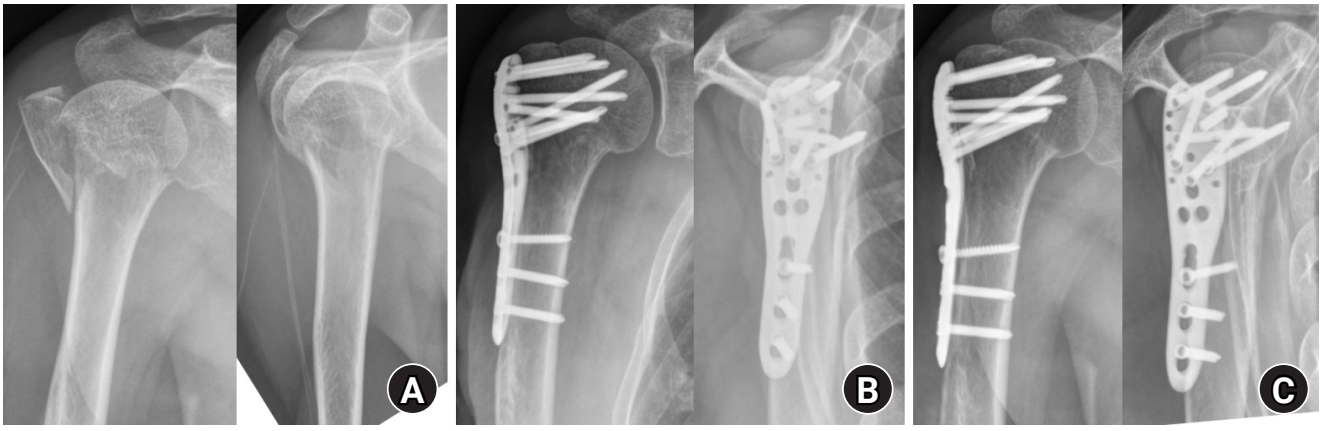



**Fig. 4.** Representative radiographs of a proximal humerus fracture treated with minimally invasive plate osteosynthesis through a deltoid-splitting approach. (A) Preoperative anteroposterior and axial radiographs showing a displaced proximal humerus fracture. (B) Immediate postoperative radiographs showing restoration of alignment and fixation with a locking plate inserted using a minimally invasive technique. (C) Final follow-up radiographs showing successful fracture union with maintained reduction and stable implant position, without evidence of fixation failure.


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However, outcomes in four-part fractures remain comparatively less favorable than those observed in two- and three-part fractures. Careful reduction of comminuted proximal humerus fractures is particularly important for restoration and maintenance of the neck-shaft angle. When adequate reduction cannot be reliably achieved using a minimally invasive approach, timely conversion to an open technique should be considered. In a prospective randomized clinical trial comparing MIPO with conventional open plating, the authors similarly reported no significant differences in functional outcomes or radiographic parameters between the two groups, although operative time was significantly shorter in the MIPO group [27]. Kim et al. [31] compared inferomedial screw augmentation with fibular strut allograft augmentation in proximal humerus fractures with medial comminution treated using MIPO. They reported superior radiographic stability and lower rates of surgical failure in the fibular allograft group, particularly in four-part fractures.

## Humeral shaft fracture

MIPO for humeral shaft fractures is particularly advantageous for fracture patterns that are amenable to healing under conditions of relative stability, including long oblique, spiral, comminuted, and segmental fracture configurations. Because the technique relies on bridge plating and indirect reduction without interfragmentary compression, it is generally less suitable for simple transverse fractures, which typically require absolute stability to facilitate primary bone healing [32,33]. Preservation of fracture hematoma and periosteal blood supply under these low-strain conditions promotes secondary callus formation, which constitutes the biological foundation of minimally invasive fixation techniques. The applicability of MIPO in the humeral shaft is further supported by the unique anatomical and biomechanical characteristics of this region. The radial nerve courses obliquely along the spiral groove and transitions from posterior to anterior within the distal third of the humerus, rendering extensive exposure during conventional open plating potentially hazardous. In this context, anterior MIPO permits fracture stabilization while minimizing direct manipulation within this zone of neurovascular vulnerability [3]. Indirect reduction methods include manual traction, external fixator-assisted reduction, joystick techniques using Kirschner wires or Schanz pins, and reduction utilizing the plate itself in combination with screws or a collinear clamp [10]. Biomechanically, the humeral shaft is subjected predominantly to torsional and bending stresses rather than axial loading forces. Consequently, bridge plating under conditions of relative stability is particularly well suited to comminuted and segmental fracture patterns, in which preservation of fracture biology may enhance secondary callus formation and fracture healing [34]. Furthermore, compared with intramedullary nailing, anterior plate fixation avoids violation of the rotator cuff tendon while still permitting reliable restoration of humeral length, coronal alignment, and rotational profile [35,36]. When meticulously performed, MIPO enables indirect fracture reduction using the plate as a reduction aid, thereby minimizing soft-tissue disruption while maintaining sufficient biomechanical stability to facilitate fracture healing [10].

### Surgical procedure

For MIPO of humeral shaft fractures, the patient is positioned supine on a radiolucent table with the affected arm freely draped to allow unrestricted manipulation during reduction. The elbow is maintained in flexion with the forearm supinated to move the radial nerve away from the anterior surface of the humerus. Fluoroscopy is positioned perpendicular to the operating table to obtain true anteroposterior and lateral images throughout the procedure.

A limited proximal incision is created through the deltopectoral interval, whereas the distal window is made over the anterior aspect of the distal humerus several centimeters proximal to the elbow crease. Unlike the conventional anterolateral approach used in open plating, this direct anterior approach minimizes the risk of radial nerve injury. The biceps muscle is retracted medially, and the brachialis is split longitudinally to expose the anterior cortex. During distal exposure, particular attention should be paid to the musculocutaneous nerve along the medial border of the brachialis muscle. Because the radial nerve remains protected posteriorly by the lateral portion of the brachialis muscle, routine exploration of the nerve is generally unnecessary.

An extraperiosteal tunnel is developed along the anterior humeral surface using blunt dissection, connecting the proximal and distal windows. The plate is typically

advanced from distal to proximal along the anterior cortex. Indirect reduction is facilitated by first securing the proximal fragment to the plate. After confirming proper alignment between the plate and proximal shaft under fluoroscopy, provisional fixation is achieved using a drill bit or temporary fixation device inserted through the proximal plate hole. A cortical screw is then inserted to bring the humeral shaft toward the plate and establish reduction. Because the plate functions as an extension of the proximal fragment, accurate proximal alignment is essential for restoration of length, coronal alignment, and rotation.

Following manual or indirect reduction of the distal fragment, temporary distal fixation is obtained in a similar manner. Additional cortical screws may be used to fine-tune reduction before insertion of definitive locking screws proximally and distally. Final fluoroscopic assessment should confirm restoration of alignment and rotational profile. Comparison with the contralateral extremity is helpful to minimize rotational malalignment.

Particular caution is required during distal screw insertion because the radial nerve crosses the posterior aspect of the humerus approximately 12–16 cm proximal to the lateral epicondyle. This region corresponds to the transition zone of the radial nerve from the posterior to the anterior compartment and therefore represents the area of greatest vulnerability during bicortical drilling and distal screw insertion. In this region, careful drilling and consideration of unicortical fixation may reduce the risk of iatrogenic nerve injury. The overall objective of fixation is stable bridge plating while preserving fracture biology and minimizing soft-tissue disruption.

### Clinical outcomes

Shin SJ et al. [10] reported the clinical outcomes of MIPO in 21 patients with humerus midshaft fractures. Radiographic union was achieved in 20 patients at a mean of 17.5 weeks postoperatively (Fig. 5). In two patients, intraoperative conversion to open reduction was required because of technical failure of the minimally invasive technique. One patient developed nonunion, and one patient experienced malunion. According to the University of California Los Angeles (UCLA) Shoulder Rating Scale,

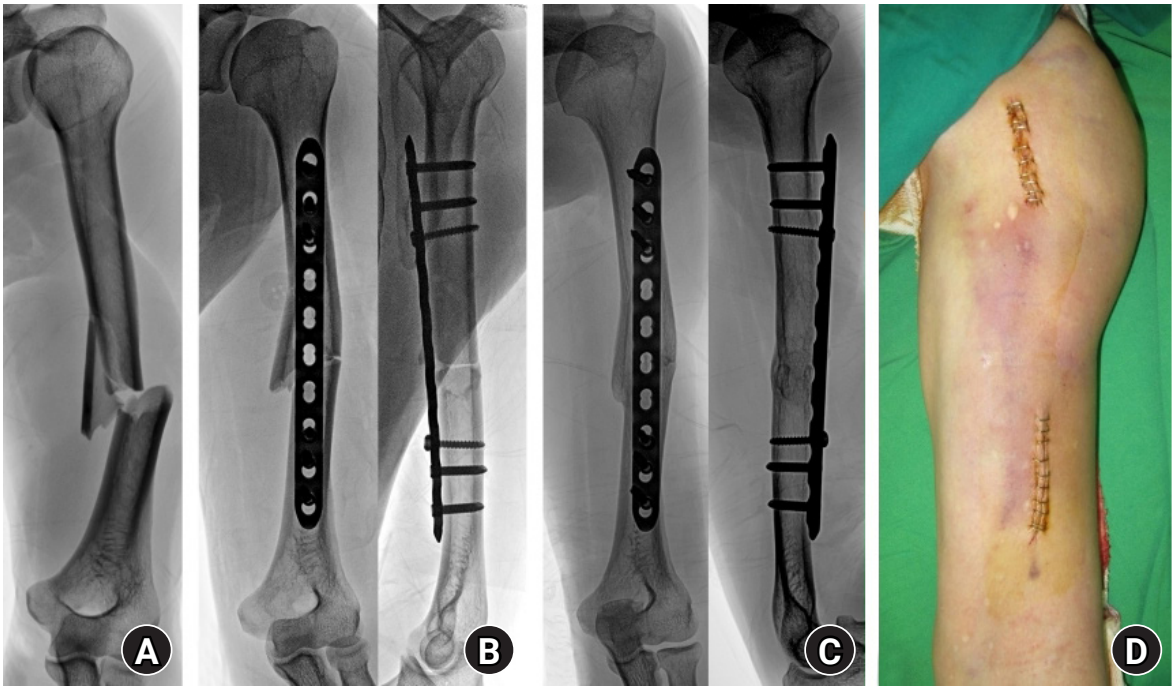



**Fig. 5.** A 34-year-old male patient with an AO/OTA 12B2 humeral shaft fracture. (A) Preoperative radiographs showing a displaced wedge-type fracture. (B) Immediate postoperative radiographs after minimally invasive plate osteosynthesis with bridge plating fixation. (C) Radiographs obtained 12 months postoperatively showing solid radiographic union with satisfactory alignment. (D) Clinical photograph showing the limited surgical windows used for minimally invasive plate osteosynthesis.


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18 patients achieved excellent results and three achieved good outcomes. No neurological complications were observed in this series. Randell et al. [3] compared outcomes between 28 patients treated using MIPO and 28 patients treated using ORIF for humeral shaft fractures and reported no significant differences in radiographic alignment or Disabilities of the Arm, Shoulder and Hand (DASH) scores between the two groups; however the overall complication rate was significantly lower in the MIPO group. External fixator-assisted reduction has been described as a useful adjunctive technique during MIPO for humeral shaft fractures. By inserting Schanz pins into the proximal and distal fragments and connecting them with a unilateral external fixator, restoration and maintenance of length, alignment, and rotational control can be achieved during plate insertion [37]. In a comparative study by Kulkarni et al. [38] evaluating humeral diaphyseal fractures, 44 patients treated with intramedullary nailing, 34 treated with ORIF, and 34 treated with MIPO were analyzed. The mean time to union was significantly shorter in the intramedullary nailing group (12.7 weeks) than in the MIPO group (14.5 weeks) and the ORIF group (13.6 weeks). However, nonunion did not occur in any patient treated with MIPO, compared with five patients in the ORIF group and ten patients in the intramedullary nailing group, representing a statistically significant difference. The UCLA Shoulder Rating Scale was significantly higher in the MIPO group, whereas the Mayo Elbow Performance Score (MEPS) demonstrated no significant differences among the three treatment groups. Overall, when considering nonunion rates, functional outcomes, and complication profiles collectively, MIPO demonstrated superior clinical outcomes compared with the alternative treatment modalities.

Although MIPO for humeral shaft fractures is technically demanding, available evidence suggests that it can provide satisfactory union rates and favorable restoration of shoulder and elbow function. Nevertheless, meticulous attention to fracture reduction techniques and fixation strategy remains essential to minimize postoperative complications such as malreduction and nonunion.

## Distal humeral shaft (extra-articular) fracture

Extra-articular distal humerus fractures present substantial challenges for internal fixation because the distal fragment is frequently short, osteoporotic, and subjected to complex bending and rotational stresses, thereby increasing the risk of fixation failure with conventional plating techniques. To address these challenges, both anterior and posterior plating strategies have been described for MIPO [39]. Anterior plating avoids routine radial nerve dissection and has been associated with shorter operative time and a lower risk of iatrogenic radial nerve injury. In addition, the anterior approach facilitates insertion of a greater number of distal screws and is associated with fewer implant-related symptoms. However, when the fracture extends distally toward the olecranon fossa, the anterior approach may be limited because the distal fragment may not provide sufficient space to accommodate the number of screws required for stable fixation. In contrast, posterior plating offers several mechanical advantages, including plate placement along a relatively flat posterior surface, fixation along the tension side of the humerus, direct visualization of the radial nerve, and improved lateral column fixation of the distal fragment [40]. However, posterior plating requires radial nerve dissection and is associated with a higher incidence of implant-related symptoms secondary to plate prominence beneath the relatively thin posterior soft-tissue envelope. Consequently, meticulous preoperative planning of plate position and distal screw configuration is essential to achieve stable fixation within this anatomically constrained region [41]. In summary, anterior plating offers the advantages of avoiding routine radial nerve dissection, reduced implant prominence, and the ability to accommodate a greater number of distal screws, although fixation may be limited in very distal fracture patterns. Posterior plating provides excellent visualization of the radial nerve and favorable distal fixation along the tension side of the humerus but requires nerve dissection and is associated with a higher incidence of implant-related symptoms. Inverted proximal humeral internal locking system (PHILOS) plating represents a useful modification of anterior plating that may improve distal fixation through multiple divergent locking screws while preserving the biological advantages of a minimally invasive approach. The use of an inverted PHILOS plate, originally designed for proximal humerus fractures, has been proposed as an alternative fixation option for extra-articular distal humerus fractures [42]. Owing to its precontoured geometry and divergent locking screw

configuration, the inverted PHILOS plate may permit secure fixation of the distal fragment while preserving the advantages of a minimally invasive approach.

### Surgical procedure

The patient is positioned supine on a radiolucent operating table with the affected arm left free to allow intraoperative manipulation and fluoroscopic assessment. A longitudinal distal incision approximately 5 cm in length is created over the anterior aspect of the distal humerus. The interval is developed by retracting the biceps muscle medially and splitting the brachialis muscle longitudinally to expose the anterior humeral cortex. Because the radial nerve remains protected posteriorly by the lateral portion of the brachialis muscle, routine radial nerve exploration is generally unnecessary unless preoperative nerve palsy is present.

After exposure of the distal humerus, a submuscular extraperiosteal tunnel is created proximally along the anterior surface of the humeral shaft using blunt dissection with a periosteal elevator. In cases with residual coronal deformity, indirect reduction may be achieved using a temporary Schanz pin inserted into the lateral condyle as a joystick to correct varus or valgus malalignment (Fig. 6A).

An inverted PHILOS plate is then passed along the anterior humeral surface through the prepared tunnel. Under fluoroscopic guidance, the distal portion of the plate is positioned over the distal fragment and provisionally stabilized using a locking drill bit. A cortical screw inserted through the combi-hole is subsequently used to draw the distal fragment toward the plate, thereby restoring sagittal alignment and bone-plate contact.

Attention is then directed to the proximal fragment. Rotational alignment is corrected using a temporary Kirschner wire while the rotational profile of the proximal humerus is assessed fluoroscopically. Coronal alignment between the plate and humeral shaft is confirmed on the anteroposterior view in a manner similar to standard MIPO techniques for humeral shaft fractures. Additional cortical screws are inserted sequentially to reduce the proximal humeral fragment (Fig. 6B, C).

Final fixation is achieved using three or four bicortical screws in the proximal fragment according to bridge plating principles and appropriate plate-screw density, while the distal fragment is secured with multiple locking screws whenever feasible. Careful drilling and accurate screw-length measurement are particularly important because the proximal locking holes of the inverted PHILOS plate have divergent trajectories.

Postoperatively, the arm is supported in a sling for approximately 4 weeks. Passive and active range-of-motion exercises of the shoulder and elbow are initiated early as tolerated.

### Clinical outcomes

Sohn and Shin [42] evaluated 23 patients with extra-articular distal humeral fractures treated using a modified application of an inverted PHILOS plate, including both open and minimally invasive techniques (Fig. 7). Radiographic union was achieved in all patients at a mean of 20.8 weeks, with excellent functional outcomes reflected by a mean MEPS of 97.6 and without major complications requiring reoperation. However, these outcomes represent a mixed cohort treated with both open and minimally invasive techniques and therefore cannot be attributed exclusively to MIPO. Notably, application of the inverted PHILOS plate permitted insertion of a greater number of locking screws into the distal fragment (mean, 5.6), thereby increasing plate-screw density and improving distal fixation stability [42].

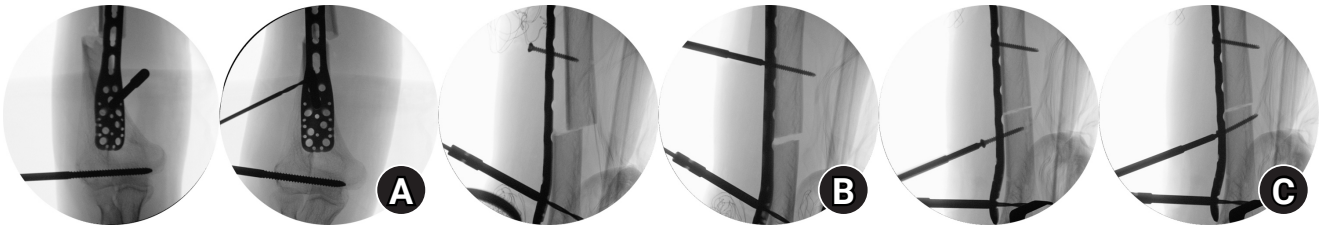



**Fig. 6.** Representative fluoroscopic images showing key reduction maneuvers during minimally invasive plate osteosynthesis for an extra-articular distal-third humeral shaft fracture. (A) Correction of varus-valgus malalignment using a temporary Schanz pin inserted into the lateral condyle as a joystick. (B, C) Sequential reduction of the proximal fragment using temporary Kirschner-wire fixation and cortical screw insertion to restore rotational and coronal alignment before definitive fixation.


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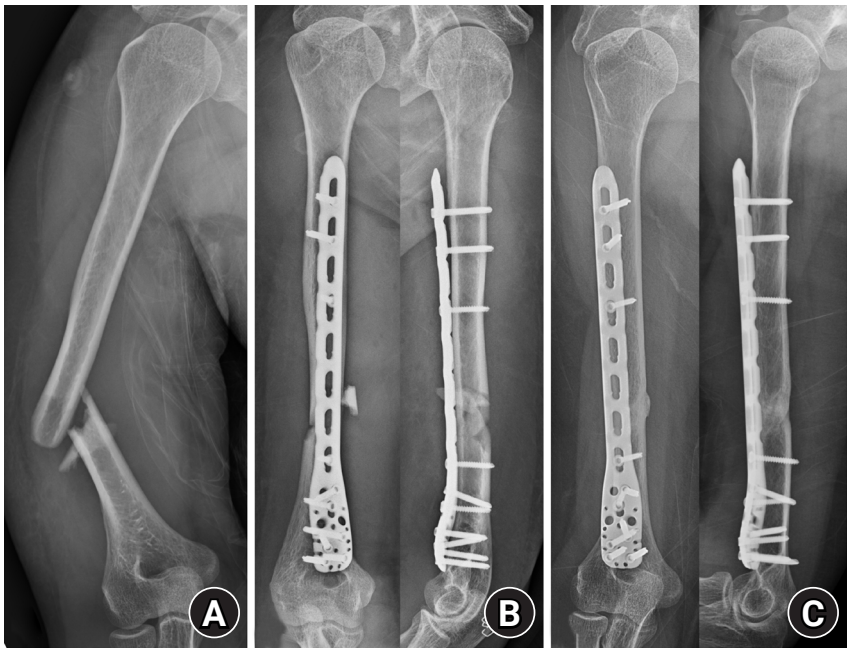



**Fig. 7.** (A) Preoperative radiographs of a 55-year-old female patient with an extra-articular distal-third humeral shaft fracture. (B) Immediate postoperative radiographs showing fixation with an inverted proximal humeral internal locking system plate applied using a minimally invasive technique. (C) Radiographs obtained 13 months postoperatively showing solid bony union without loss of alignment or implant-related complications.

In a subsequent comparative study, anterior plating using the modified PHILOS technique was compared with posterior plating using an extra-articular distal humerus plate. Both techniques demonstrated satisfactory clinical and radiographic outcomes, with no significant differences in union rate, elbow range of motion, or functional scores. However, anterior plating was associated with significantly shorter operative time, greater distal screw density, and a markedly lower incidence of implant-related symptoms. In contrast, posterior plating was frequently associated with implant prominence and postoperative discomfort, resulting in a higher rate of secondary implant removal [39]. Similarly, Jitprapaikulsarn et al. [43] reported favorable outcomes following anterior MIPO using an inverted PHILOS plate in 12 patients. All fractures achieved radiographic union without loss of reduction, implant failure, infection, or iatrogenic nerve injury. Functional outcomes were excellent, and no secondary procedures were required during follow-up. These findings further support the reproducibility and safety of anterior MIPO using an inverted PHILOS plate in centers other than the original developer institution. Collectively, these findings suggest that anterior MIPO using an inverted PHILOS plate can provide reliable fracture union and favorable functional outcomes while offering distinct advantages with respect to distal fixation stability and implant-related morbidity.

## Conclusions

Clinical evidence has demonstrated that when appropriate indications are selected and anatomical safe zones are meticulously respected, MIPO can provide the biological advantages of limited soft-tissue disruption, preservation of periosteal vascularity, and high rates of fracture union while maintaining satisfactory functional recovery. However, surgeons should recognize the inherent limitations of indirect reduction techniques and maintain a low threshold for conversion to open procedures when adequate reduction or stable fixation cannot be reliably achieved.

Ultimately, MIPO around the shoulder girdle should be regarded as a technically demanding yet highly valuable surgical strategy, with successful clinical outcomes largely dependent on precise indication selection, meticulous surgical planning, appropriate window placement, accurate

plate insertion sequence, and comprehensive understanding of regional neurovascular anatomy. From a practical perspective, MIPO is generally favored for multifragmentary, long oblique, spiral, comminuted, and segmental fracture patterns in which indirect reduction and biologic fixation can be effectively utilized. In contrast, conventional open plating may be more appropriate for simple fracture configurations requiring anatomical reduction and absolute stability, irreducible fractures, or situations in which safe implant placement cannot be reliably achieved through limited surgical exposure. Ultimately, the choice between MIPO and open plating should be individualized according to fracture morphology, bone quality, soft-tissue condition, and surgeon experience.

Nevertheless, the current body of evidence remains limited, as most available studies are retrospective, single-center investigations with relatively small sample sizes. Although several comparative studies and a limited number of randomized trials have reported encouraging outcomes, higher-level evidence remains insufficient to establish definitive superiority of MIPO over conventional fixation techniques across all fracture patterns. Furthermore, the learning curve associated with indirect reduction techniques and the increased reliance on intraoperative fluoroscopy should be recognized when adopting these procedures. Future prospective multicenter studies and well-designed comparative trials are warranted to further define optimal indications, evaluate long-term outcomes, and clarify the relative benefits of MIPO in different fracture configurations.

## Article Information

### Author contributions

Conceptualization: HSS, SJS. Data curation: HSS, YC. Methodology: SJS. Resources: HSS. Supervision: SJS. Validation: HSS. Writing-original draft: HSS, YC. Writing-review & editing: HSS, SJS. All authors read and approved the final manuscript.

### Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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### Data availability

Not applicable.

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### Supplementary materials

None.

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# Locked plating in older patients with distal femur fractures: strategies to avoid complications

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Distal femur fractures in older patients with osteoporosis are difficult to treat because poor bone quality reduces screw purchase and fixation stability. Minimally invasive locked plating with an angularly stable locking compression plate is widely used to obtain secure fixation in osteoporotic distal femur fractures and offers improved biomechanical performance. However, complications such as implant failure and peri-implant fracture continue to occur. This narrative review summarizes current principles of minimally invasive lateral locked plating for osteoporotic distal femur fractures in older patients and discusses practical strategies to reduce fixation-related complications based on the available literature and the author's clinical experience.

**Level of evidence:** Not applicable.

**Keywords:** Distal femoral fractures; Osteoporotic fractures; Lateral locked plating; Complications

Review Article

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## Introduction

Distal femur fractures in elderly patients are prone to fixation failure due to decreased bone quality and fixation strength associated with osteoporosis [1-3]. Surgical treatment options commonly include intramedullary (IM) nailing and locked plating. Although IM nailing offers certain biomechanical advantages over plate fixation, it has several limitations. These include difficulty in achieving stable fixation and preventing malalignment due to the wide metaphyseal canal of the distal femur, often necessitating additional procedures such as Poller screw placement. Furthermore, its use is restricted in cases with comminuted metaphyseal fractures, intra-articular extension, or in patients with prior hip or knee arthroplasty.

Consequently, plate fixation remains the most common osteosynthesis method for distal femur fractures in the elderly. Recently, with the introduction of advanced techniques such as bridging plating and minimally invasive surgery, as well as anatomically contoured plates designed to match the distal femur morphology, locked plating has become widely adopted.

Recent studies have emphasized the importance of individualized fixation strategies based on fracture pattern, bone quality, and patient frailty. In particular, augmentation techniques such as cement augmentation, dual plating, and nail-plate combination constructs have gained attention as viable options to enhance fixation stability in osteoporotic distal femur fractures [4-6]. However, except for far distal femur fractures, lateral locked plating alone is generally sufficient to achieve favorable

clinical outcomes, as it provides adequate fixation stability by ensuring sufficient screw purchase in the distal fragment and maintaining an appropriate working length in most fracture patterns [7,8].

When performing lateral locked plating in elderly patients with distal femur fractures, it is crucial to prevent malalignment through indirect reduction and to achieve proper stabilization based on a precise understanding of locking plate mechanics. Therefore, this narrative review aims to summarize the therapeutic principles of lateral locked plating in elderly patients with distal femur fractures and to provide practical recommendations for avoiding surgical complications based on published evidence and the author's clinical experience.

This review is an expanded and updated version of the author's previous review published in the Journal of the Korean Fracture Society in 2019 [9]. Compared with the earlier article, the present review incorporates recent evidence regarding augmentation techniques such as nail-plate combination constructs, far cortical locking, and controlled dynamization strategies, and provides an updated discussion of fixation biomechanics and complication-prevention strategies in elderly patients with osteoporotic distal femur fractures.

### Ethics statement

Written informed consent was obtained from the patients for publication of their images in this review.

## Characteristics of locking plates

After Mast et al. [10] described the advantages of indirect reduction without exposing the fracture site and introduced the concept of biological plate fixation, several studies [11-13] have reported that bridging plating can reduce the time to bone union, decrease the need for bone grafting, lower the incidence of complications such as infection, and yield better functional outcomes. Locking plates provide stability through the locking mechanism between the screw and the plate, which minimizes compression of the plate against the cortical bone. This helps preserve periosteal blood supply while maintaining mechanical stability, making them particularly useful for minimally invasive percutaneous plate osteosynthesis (MIPO). In addition, with the development of anatomical pre-shaped plates, precise intraoperative anatomical contouring of the plate is no longer necessary. This reduces operative time and prevents primary reduction loss caused by inaccurate plate contouring during surgery [14].

Furthermore, the locking mechanism prevents micromotion between fracture fragments, resulting in relatively higher pull-out strength [15]. Consequently, secondary loss of reduction during postoperative follow-up is less frequent. Because the structural stability of a locking plate construct does not rely solely on the screw's purchase in the bone, it is exceptionally effective for treating osteoporotic distal femur fractures in elderly patients [16-19].

Despite these advantages, locking plates may create excessively rigid constructs, potentially suppressing interfragmentary micromotion necessary for secondary bone healing. Recent biomechanical and clinical evidence suggests that controlled dynamization strategies, including far cortical locking or selective screw omission near the fracture site, may improve healing outcomes by optimizing construct flexibility [20,21].

## Indirect reduction

In indirect reduction of distal femur fractures, the key considerations include preservation of femoral length, rotation, and functional alignment. Femoral length and rotation can be restored by comparison with the contralateral limb, while the use of an anatomical plate can aid in maintaining functional alignment in both coronal and sagittal planes.

For reduction in the sagittal plane, a bump placed beneath the distal thigh can facilitate reduction. If this method is insufficient to maintain reduction, a Schanz screw may be additionally used to hold the reduction (Fig. 1). Femoral length should be restored and maintained through manual or skeletal traction.

For reduction in the coronal plane, instruments such as a long hemostatic clamp or pusher can be used. Temporary maintenance of reduction can be achieved with a collinear reduction clamp or percutaneous cerclage wiring. In addition, indirect reduction can be facilitated by compressing the proximal fragment to the plate using a conventional cortical screw (Fig. 2).


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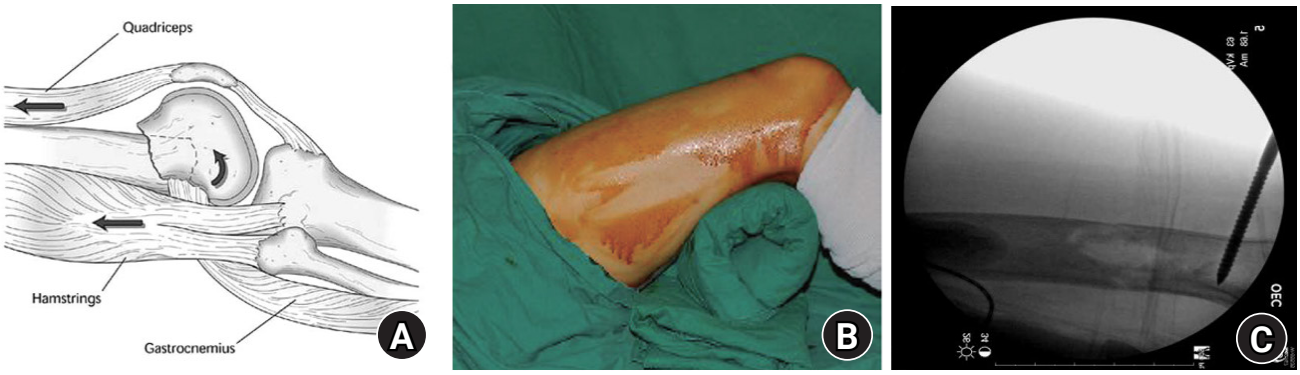



**Fig. 1.** Indirect sagittal-plane reduction of a distal femur fracture. (A) Posterior angulation caused by deforming forces of the surrounding muscles. (B, C) Reduction using a bump beneath the distal thigh or a Schanz screw.

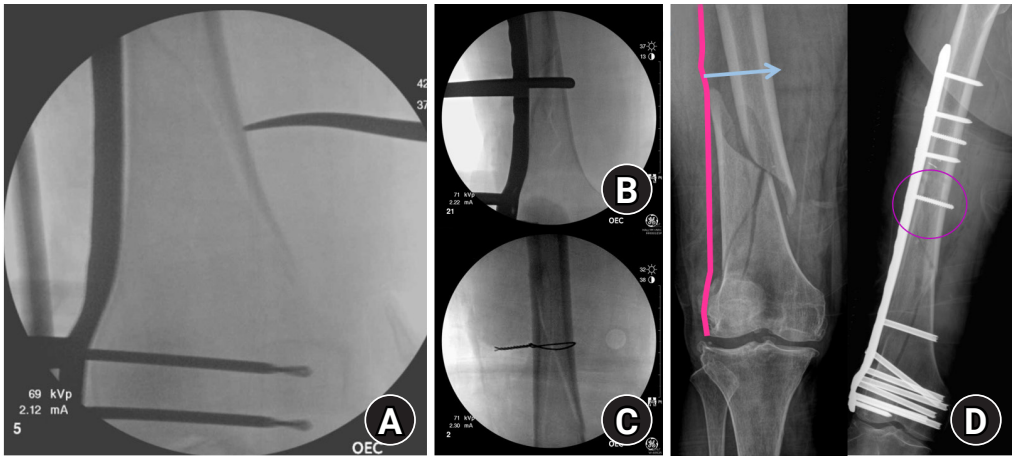



**Fig. 2.** Coronal-plane reduction methods for distal femur fractures using (A) a long hemostatic clamp, (B) a collinear reduction clamp, (C) percutaneous cerclage wiring, or (D) a conventional screw. In (D), the arrow indicates the insertion site of the conventional cortical screw, and the circle indicates the screw inserted to reduce the fracture site.

## Internal fixation using locking plates

### Plate length

In conventional plating, surgeons tended to select shorter plates to minimize soft tissue damage around the fracture. However, when performing MIPO using locking plates for distal femur fractures, it is, conversely, important to use the longest possible plate [22]. The minimum length of a locking plate is influenced by two factors: plate span width and plate-screw density (Fig. 3) [23]. Plate span width is defined as the ratio of plate length to the overall fracture length. For comminuted fractures, a plate length of 2-3 times the fracture length is recommended, whereas for simple fractures, a plate length of 8-10 times the fracture length is advised.

Elderly patients with distal femur fractures are at risk of subsequent hip fractures, in which case space for hip nailing or screw fixation is required. Therefore, the plate should be extended as far as possible to just below the lower margin of the lesser trochanter. The use of a short locking plate in simple fractures results in a reduced working length, leading to high strain at the fracture site on the plate and an increased risk of fixation failure (Fig. 4). To prevent this, the use of a sufficiently long plate or dual plating is recommended.

Plate-screw density is defined as the ratio of the number of inserted screws to the total number of screw holes in the plate. A density of 0.4-0.5, meaning that fewer than half of the available screw holes are filled, is recommended [24]. In plates with fewer than 12 screw holes, maintaining a plate-screw density below 0.5 is difficult; therefore, the use of locking plates with at least 12 screw holes is recommended.

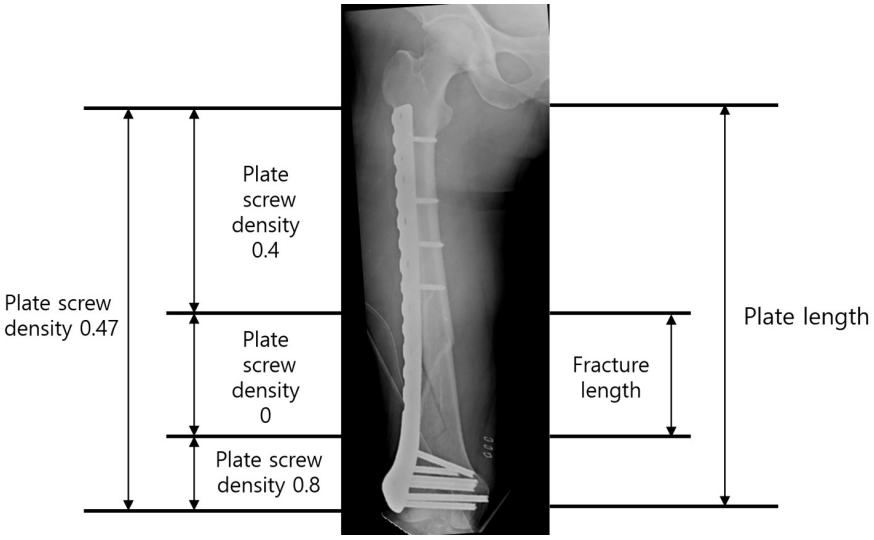



**Fig. 3.** Appropriate plate length and plate-screw density after minimally invasive plate osteosynthesis using a locking plate for an osteoporotic distal femur fracture.

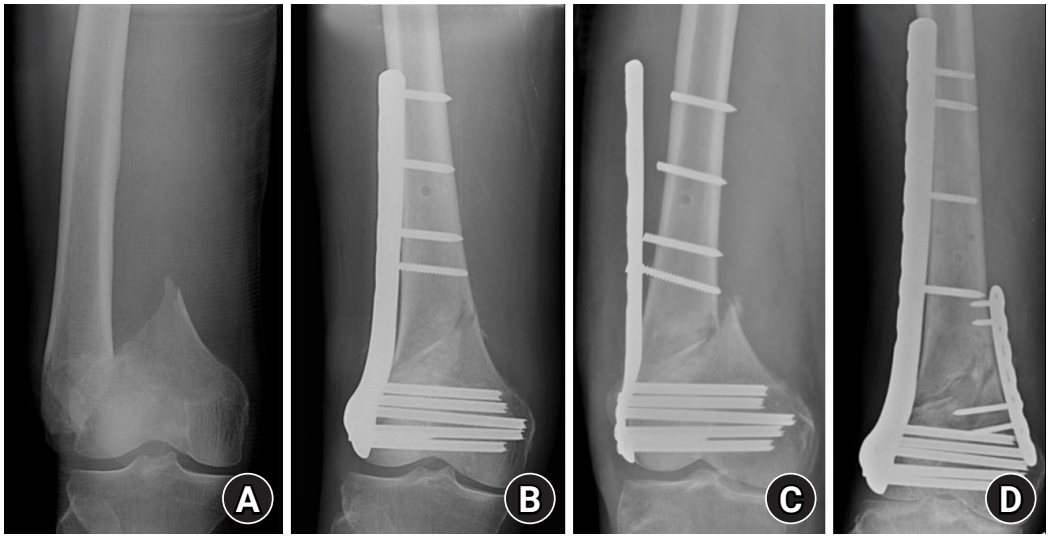



**Fig. 4.** (A) Distal femur fracture in a 70-year-old male patient. (B) Postoperative radiographs after minimally invasive locked plating. (C) Fixation failure with broken locking screws 2 months after surgery. (D) Anteroposterior and lateral radiographs obtained 7 months after double plating.

### Plate position

In a normal distal femur, the lateral cortex is inclined approximately 10° medially relative to the sagittal plane in the axial plane, and an anatomical locking plate is positioned on the anterolateral aspect of the distal femur. Therefore, during lateral locked plating, the plate should be positioned such that the screw holes are slightly visible on the anteroposterior view, while on the lateral view, the anterior surface of the plate appears parallel to or slightly anterior to the anterior cortex of the femur. This positioning allows the plate to be placed parallel and in close contact with the anterolateral cortical surface of the femur (Fig. 5).

### Screw type, position, and number

In locking plates, four types of screws can be used. Conventional cortical and cancellous screws allow insertion at various angles, whereas locking screws require precise insertion because the stability is significantly reduced if


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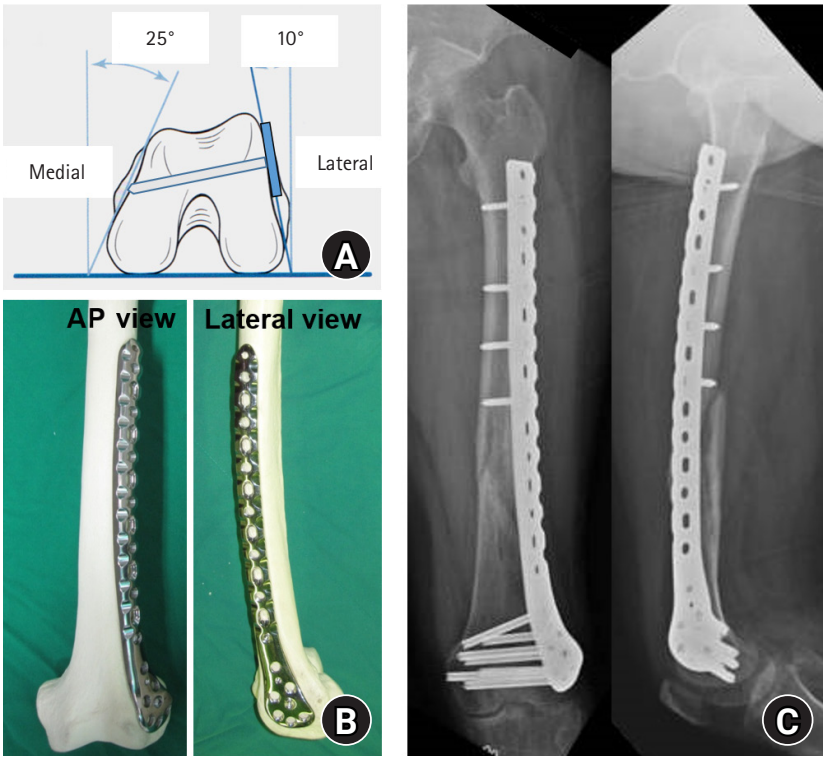



**Fig. 5.** (A) Schematic drawing showing the axial morphology of the distal femur and appropriate distal locking screw length. (B) Anteroposterior (AP) and lateral photographs showing the appropriate position of a lateral anatomical locking plate in a distal femur model. (C) Anteroposterior and lateral radiographs showing appropriate locking plate position after fixation of a distal femur fracture in a 72-year-old female patient.

the insertion angle deviates by more than 5°. Therefore, the use of a locking drill guide is essential for accurate screw placement [25]. In cases where locking screws achieve unicortical fixation, the working length of the screw becomes shorter and the construct is more vulnerable to torsional forces; thus, bicortical fixation is generally recommended in elderly patients with distal femur fractures [24].

Regarding screw positioning, Stoffel et al. [22] reported that the working length of the plate—defined as the distance between the two nearest screws on either side of the fracture—affects axial stiffness and torsional rigidity. In osteoporotic distal femur fractures, it is important to secure a sufficient working length by leaving at least one empty screw hole on each side of the fracture site. This strategy reduces local stress concentration on the plate, improves fatigue strength, and allows controlled micromotion at the fracture site, thereby promoting callus formation and secondary bone healing.

With regard to the number of screws, increasing the screw number beyond a certain point does not significantly improve stability and may even hinder secondary bone healing. In general, the use of at least 3-4 screws per main fragment is recommended. Stoffel et al. [22] demonstrated that more than three screws per fragment did little to increase axial stiffness and that a fourth screw did not increase torsional rigidity. In elderly patients with distal femur fractures, it is recommended to distribute four screws (at least three) in the proximal fragment, avoid screw insertion in the intermediate plate segment spanning the fracture to maintain sufficient working length, and insert as many screws as possible in the distal segment to secure the femoral condyle. This approach ensures stable fixation while adhering to the recommended plate-screw density.

### Distance between cortex and plate

In general, structural stability decreases as the distance between the cortical bone and the plate increases [16,22]. However, some studies have reported that when contact between the plate and cortical bone is reduced (when the distance between the bone and plate increases) and great-

er strain is applied, the cross-sectional area of the construct increases, which can promote secondary bone healing and ultimately result in greater in vivo strength after surgery [26]. A recent study comparing locking plates with dynamic compression plates recommended maintaining the distance between the cortical bone and the locking plate at less than 2 mm [27].

### Augmentation techniques

To improve fixation strength in osteoporotic distal femur fractures, several augmentation strategies have been introduced. Cement augmentation around screws has been shown to increase pull-out strength and improve fixation in severely osteoporotic bone [28]. Dual plating, particularly the addition of a medial plate, provides enhanced resistance to varus collapse and is especially useful in comminuted fractures or those with medial cortical deficiency [29]. In addition, nail-plate combination constructs have recently emerged as an effective strategy, combining the biomechanical advantages of IM nailing and lateral locked plating. These constructs improve load sharing and reduce the risk of implant failure, particularly in highly unstable fracture patterns [30]. However, these techniques require careful surgical planning and may increase operative time and soft tissue dissection.

## Precautions for lateral locked plating

Lateral locked plating, when used in a minimally invasive manner for complex distal femur fractures, may be associated with several complications. Reported rates of healing complications, including nonunion, delayed union, and implant failure, range from 0% to 32%, and implant failures tend to occur late, with 75% of failures occurring after 3 months and 50% after 6 months [31]. To address these issues, it is essential to establish a thorough preoperative plan and to strictly adhere to the principles of fixation using a locking plate [19].

When performing indirect reduction, achieving reduction of the fracture site is a prerequisite. Attempting to obtain reduction using the plate itself increases the risk of malalignment; therefore, the use of various traction devices, a Schanz pin, or conventional screws is recommended to facilitate reduction. However, with indirect reduction techniques, there remains a risk of angular or rotational deformities due to imperfect overall alignment. In particular, osteoporotic femurs in elderly patients often exhibit significant bowing, which can predispose to malalignment. Thus, intraoperative assessment of length and rotational and angular alignments is critical. To prevent this malalignment, comparison with the contralateral limb and obtaining an accurate lateral view is necessary both preoperatively and intraoperatively. In some cases, a temporary external fixator may be used to maintain reduction and preserve overall alignment and length.

Regarding screw insertion, when a locking screw is used for the most proximal screw fixation in the proximal fragment, its larger core diameter provides greater strength compared to a cortical screw; however, it also leads to increased stress concentration, which may result in a stress-riser fracture at that site (Fig. 6). Therefore, in elderly patients with distal femur fractures treated with a locking plate, it is recommended to use a conventional cortical screw rather than a locking screw in the most proximal screw hole. Bottlang et al. [32] reported that using a cortical screw instead of a locking screw in the most proximal screw hole reduces stress concentration at the proximal end of the plate and increases resistance to bending forces. To achieve optimal fracture reduction or to ensure close apposition of the plate to the proximal fragment, cortical screws must be inserted prior to locking screws [24,33]. If a cortical screw is tightened after a locking screw has already been engaged, especially when a gap exists between the plate and bone, it can impose excessive stress on the locked screw-hole interface or the bone-screw construct. This may lead to compromised fixation strength or potential screw failure. In cases where a stress-riser fracture occurs due to locking screw fixation at the most proximal screw hole, stable fixation can be readily achieved using an overlapping IM nailing (Fig. 6) [34].

When performing locked plating, additional screw insertion at the fracture site to achieve precise reduction may increase structural stiffness at the fracture site, thereby inhibiting callus formation and leading to delayed union or nonunion. Therefore, screw insertion at the fracture site should be avoided whenever possible, and a sufficient working length should be maintained (Fig. 7) [35,36]. In locked plating, screw heads lock into the plate holes, preventing screw pull-out or loosening typically seen with conventional compression plating. However, in osteopo-


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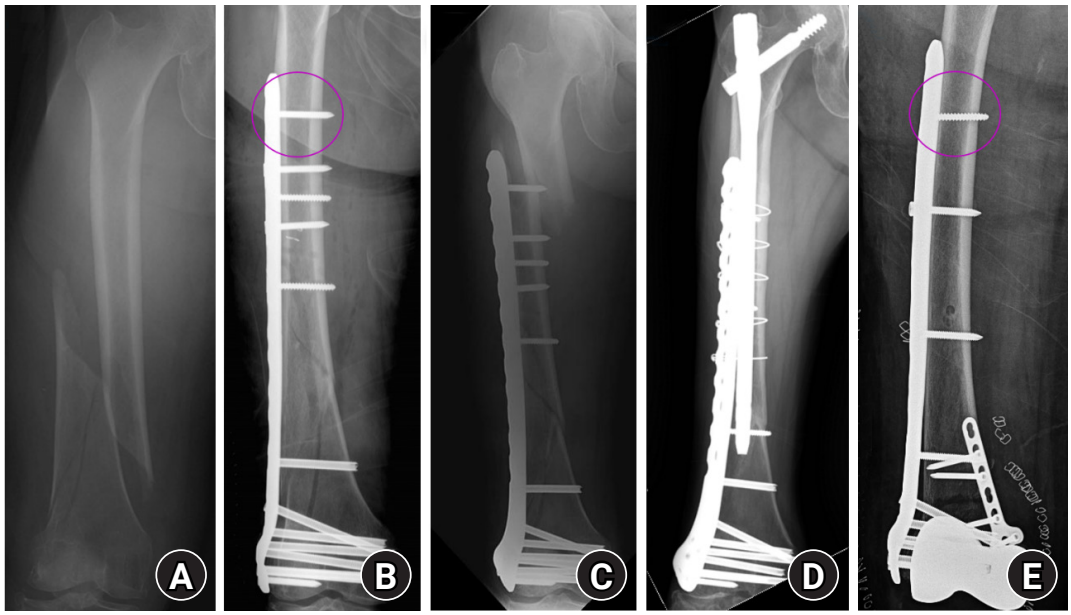



**Fig. 6.** (A) Radiograph of a distal femur fracture in a 74-year-old female patient after a ground-level fall. (B) Postoperative radiograph after closed reduction and minimally invasive locked plating, showing a locking screw in the proximal outermost screw hole (circle). (C) Six-week postoperative radiograph showing a stress-riser fracture around the outermost locking screw after a slip-and-fall injury. (D) Radiograph showing bony union 2 years after overlapping intramedullary nailing. (E) Postoperative radiograph showing locked plating with a conventional screw (circle), rather than a locking screw, in the proximal outermost screw hole to minimize the stress riser.

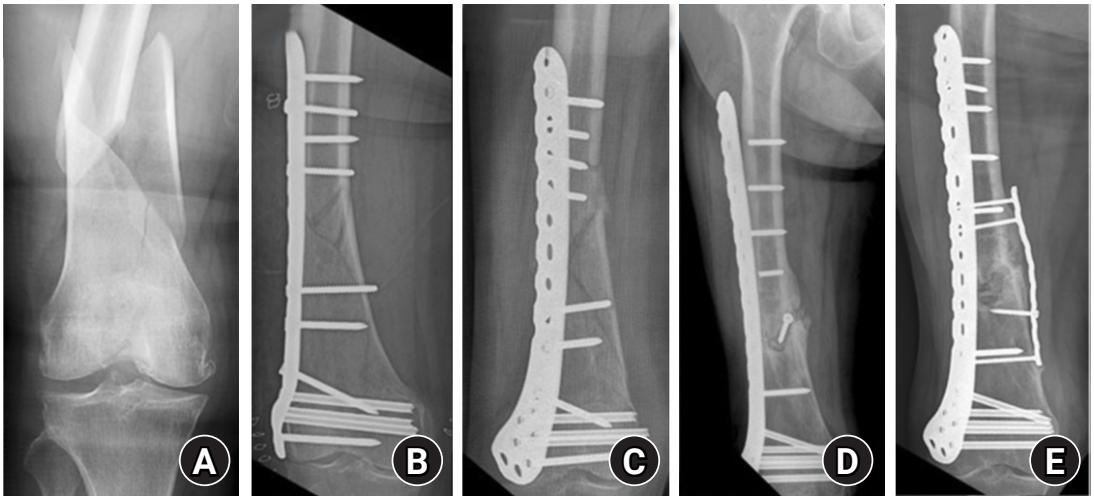



**Fig. 7.** (A) Radiograph of a 75-year-old female patient showing a spiral fracture with a butterfly fragment of the distal femur. (B) Lateral locked plating performed with two appositional screws at the fracture site. (C) Collapse of the fracture site with pull-out of the plate and proximal screws 2 months after surgery. (D) Additional fixation failure with breakage of the proximal screws after revision surgery using a longer locking plate. (E) Bony union achieved 9 months after the third operation, which included medial support plating and autologous iliac bone grafting.

rotic bone with reduced cortical strength, failure may occur in the bone surrounding the plate and screws, and in the distal femur, screws may even penetrate into the joint. In addition, early weight-bearing before sufficient bone healing may result in screw breakage, and the use of a short plate with insufficient working length may lead to plate breakage [36].

If locking screws inserted into the distal fragment pro-

trude beyond the medial cortex, they may cause soft tissue irritation and pain during joint motion. Although intraoperative fluoroscopy is used to confirm appropriate screw length, screws are often inserted longer than intended, resulting in medial protrusion. Because the medial cortical surface of the distal femur is inclined approximately 25° relative to the sagittal plane, it is important to internally rotate the femur by about 25° and obtain an anteroposterior radiograph intraoperatively to confirm whether distal locking screws have penetrated the medial cortex (Fig. 8).

Excessive distance between the plate and cortical bone may also lead to soft tissue irritation and decreased structural stability, requiring careful attention. Even in simple fractures, failure to adhere to the principles of locking plate fixation may result in delayed union, nonunion, malunion, and fixation failure [15,37]. It should also be recognized that the use of a locking plate alone does not necessarily guarantee superior mechanical strength in osteoporotic fractures; rather, a more stable construct can be achieved biomechanically by appropriately combining conventional cortical screws with locking screws [32,38].

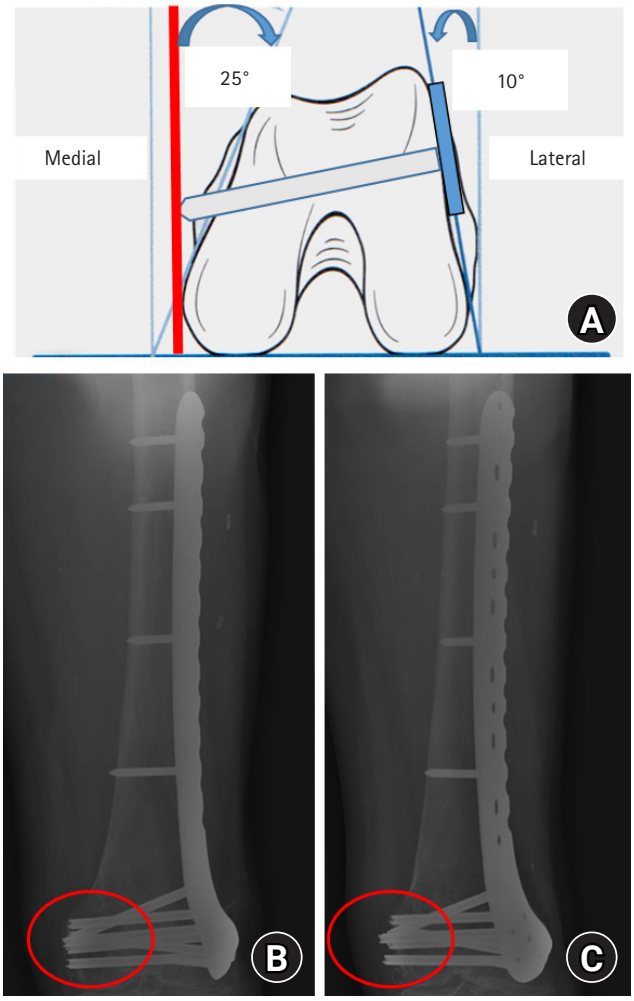



**Fig. 8.** (A) Schematic drawing showing the axial morphology of the distal femur and protrusion of a distal locking screw. (B) True anteroposterior radiograph showing appropriate distal locking screw length (circle). (C) Radiograph obtained after approximately 25° of internal thigh rotation, showing protrusion of the distal screws across the medial cortex (circle).

In the case of anatomically precontoured plates, additional intraoperative contouring is not required, and indirect fracture reduction can be achieved using the plate. However, if the entry point is improperly selected and the locking plate is not accurately positioned on the anterolateral aspect of the femur, the plate may assume an eccentric position. This can result in locking screws, which have predetermined insertion angles, failing to properly engage the cortical bone. Consequently, the plate may be positioned farther from the femur, reducing structural stability and causing soft tissue irritation. Therefore, careful attention to proper plate positioning is essential [24].

Finally, patient-related factors such as frailty, comorbidities, nutritional status, and bone metabolism should also be considered. Optimization of systemic conditions, including correction of vitamin D deficiency and appropriate osteoporosis management, may contribute to an improved biological environment for fracture healing and potentially reduce the risk of fixation failure [39].

## Conclusions

With the development of anatomically precontoured locking plates and the adoption of MIPO techniques, satisfactory outcomes using lateral locked plating have been reported in the treatment of distal femur fractures in elderly patients. However, meticulous caution is required, as fixation failure and impaired bone healing frequently occur due to poor bone quality and inadequate fixation. Therefore, more effective treatment of distal femur fractures in elderly patients can be achieved by selecting an appropriately sized plate according to the fracture pattern and bone quality and adhering to the fundamental principles of locked plating.


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All the work was done by Je-Hyun Yoo.

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# Current concepts in distal clavicle fractures: an evidence-based update

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Distal clavicle fractures (DCFs) account for 10%–30% of all clavicle fractures and remain difficult to manage because fracture stability depends heavily on coracoclavicular ligament integrity, plain radiographic classification has limited reliability, and distal fragment size varies substantially, complicating fixation planning. This review provides an evidence-based update on the anatomy, classification, imaging, and management of DCFs, incorporating recent literature, including population-specific cadaveric data and three-dimensional fracture mapping. The conoid and trapezoid ligaments have distinct osseous footprints that influence fracture stability in both the Neer/Craig and Cho classification systems; however, interobserver reliability remains only slight-to-moderate for both systems, particularly when conoid ligament integrity must be inferred. Three-dimensional computed tomography mapping has shown that posterior displacement and angulation are nearly universal but often underrecognized on standard radiographs, supporting selective computed tomography use when radiographs do not adequately characterize fracture morphology, comminution, or multiplanar displacement. Magnetic resonance imaging should be reserved for cases in which ligament integrity remains diagnostically ambiguous. Stable fractures generally have excellent outcomes with conservative treatment using a simple arm sling. For unstable fractures, operative and conservative treatment yield similar 1-year functional outcomes despite different union rates (96% vs. 63%), with conservative treatment carrying a nonunion risk of approximately one-third and operative treatment carrying a technique-dependent reoperation burden, ranging from planned implant removal in most hook plate cases to less than 10% with coracoclavicular stabilization constructs. When surgery is indicated, technique selection should be guided by fracture morphology and surgeon experience: anatomic locking plate fixation with or without coracoclavicular augmentation for Neer IIA/Cho IIA fractures, dedicated coracoclavicular stabilization for Neer IIB fractures (Cho IIB/IIC), and hook plate fixation as a salvage construct for Neer V/Cho IID fractures. Management should integrate classification, imaging findings, union risk, reoperation risk, expected recovery, and patient-specific factors through shared decision-making.

**Level of evidence:** Not applicable.

**Keywords:** Clavicle; Bone fractures; Articular ligaments; Internal fracture fixation; X-ray computed tomography

**Review Article**

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## Introduction

Distal clavicle fractures (DCFs) account for 10%–30% of all clavicle fractures and remain a challenging clinical problem due to their unique anatomical complexity and the lack of consensus on optimal management [1-6].

Fracture instability in DCFs is largely determined by the integrity of the coracoclavicular (CC) ligament complex: ligamentous integrity—not fracture morphology alone—determines stability and guides treatment, yet available classification systems demonstrate only fair-to-moderate interobserver reliability on standard radiographs [4,5,7], leaving surgeons with inconsistent classification of the same fracture pattern. Additionally, the small and often comminuted distal fragment makes surgical fixation technically demanding, and no single operative technique has demonstrated clear superiority. Nonunion rates approaching 31% with conservative treatment have prompted surgical intervention for unstable fractures [8], yet operative cohorts report aggregate complication rates exceeding 40% (implant-related pain, hardware failure, infection, scar pain, wound issue, and nonunion) and similar reoperation rates, creating an unresolved risk-benefit dilemma [8-10]. The paucity of high-quality randomized evidence comparing fixation strategies further limits the strength of current recommendations. This narrative review of the literature was conducted using PubMed and Google Scholar. Studies published between 2015 and 2025 were preferentially included, with earlier seminal works retained where appropriate. Priority was given to systematic reviews, meta-analyses, and randomized controlled trials. In this context, the present review aims to provide an evidence-based update on the classification, imaging, and surgical management of DCF, incorporating the most recent literature to guide contemporary clinical decision-making.

### Ethics statement

Written informed consent was obtained from all patients whose clinical images appear in Figs. 2–5 for publication of their imaging data.

## Surgical anatomy of the CC ligament complex

A precise understanding of CC ligament anatomy is fundamental to interpreting fracture instability and selecting fixation strategies. The CC complex comprises two components—the conoid ligament (CL) and the trapezoid ligament (TL)—each with defined osseous footprints that directly influence implant placement.

The CL originates from the posteromedial coracoid dorsum in a C-shaped configuration and ascends posterolaterally to insert on the conoid tubercle of the posteroinferior clavicle, forming an inverted cone with a tapered inferior apex [11]. Pooled data from three cadaveric studies (188 shoulders) place the center of the CL clavicular footprint at a weighted mean of 34.9 mm (range, 23.2–46.4 mm) from the lateral clavicular margin, with a footprint width of 18.0 mm and length of 5.9 mm [11]. At the coracoid, the attachment center lies approximately 35.4 mm from the coracoid tip, with a footprint of 5.4 mm width and 11.0 mm length [11]. The TL arises from the anterosuperior coracoid, anterior to the CL footprint, and courses in a posteromedial-to-anterolateral direction to attach along the trapezoid line on the anteroinferior clavicle, anterolateral to the conoid tubercle [11]. It is 2–3 times thicker at its clavicular insertion than at its coracoid origin. The center of the TL clavicular footprint lies a weighted mean of 25.3 mm from the lateral clavicle margin, with a width of 14.6 mm and length of 9.6 mm [11].

Implant design parameters for CC fixation—including TightRope tunnel intervals and suture anchor footprint targets—are largely derived from Western cadaveric datasets, raising concerns about direct extrapolation to Asian patients. A cadaveric study by Chung et al. [12] analyzing 102 Korean shoulders reported that the conoid footprint center lies 42.8±3.4 mm (men) and 39.9±3.3 mm (women) from the lateral clavicle margin—approximately 5–8 mm more medial than the Western pooled mean of 34.9 mm [11]. Trapezoid distances were comparable between populations (21.7±3.2 mm vs. 25.3 mm pooled) [11,12]. The interligament angle between CL and TL measured 25°±8° (male) and 28°±5° (female) on the anteroposterior (AP) view and 19°±3°/17°±3° on the lateral view [12], suggesting that purely vertical CC reconstruction may inadequately restore the oblique native trajectory of the CL. These findings indicate that population-adjusted landmarks warrant consideration in preoperative planning for Korean and other Asian patients.


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## Classification systems

The Craig modification of the Neer system classifies DCF into five types based on CC ligament involvement. Types I and III are stable and managed conservatively; types II and V are unstable, carrying nonunion rates of 31% with conservative treatment [8]. The clinically critical type II subclassification—IIA (the fracture line is medial to the CC ligaments) versus IIB (the fracture line is between the CL and TL)—directly governs operative strategy but is the distinction most vulnerable to misclassification on plain radiographs. Interobserver agreement for the Neer system consistently falls in the slight-to-fair range (κ=0.11–0.40) [6], and a multicenter study confirmed it carried the lowest agreement among four systems evaluated (mean κ=0.368) regardless of surgeon subspecialty [13]. Magnetic resonance imaging (MRI) reclassification changed treatment recommendations in 5% of initially radiograph-typed cases, predominantly upgrading stable fractures to operative indications [14].

The Cho classification divides fractures into type I (stable, displacement <5 mm) and type II (unstable, ≥5 mm), with type II further subclassified into four subtypes: IIA (fracture medial to the CC ligament: conoid and trapezoid intact); IIB (fracture medial to the CC ligament: conoid torn, trapezoid intact); IIC (fracture lateral to the CC ligament: both ligaments torn); and IID (comminuted fracture, CC ligaments attached to inferior fragment) (Fig. 1) [15].

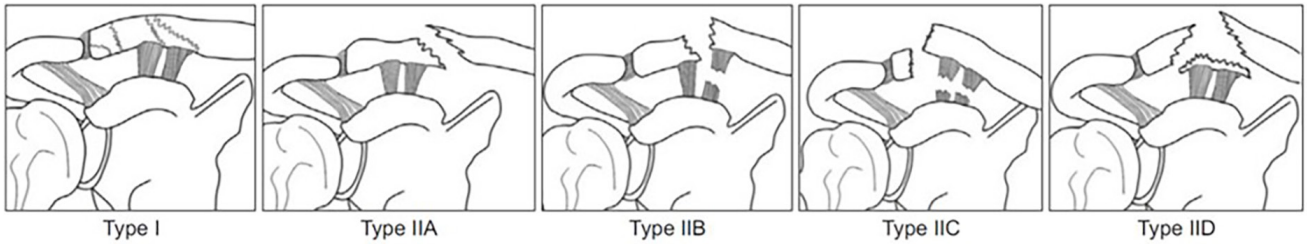
Each subtype is paired with a recommended fixation construct—locking plate for IIA and IID, CC fixation for IIB and IIC—providing treatment guidance absent from the Neer system [15]. Reliability was moderate interobserver (κ=0.434) and substantial intraobserver (κ=0.644), with no significant difference between shoulder specialists and orthopedic fellows [15].

Both systems share a common vulnerability: the Neer IIA/IIB and Cho IIA/IIB distinction depends on CL integrity, which plain radiographs cannot directly demonstrate. Routine measurement of the CC distance and fracture angle supplements classification accuracy; MRI should be considered when radiographic classification is ambiguous and the consequence of undertreating an unstable fracture is high [14].

## Imaging and diagnosis

Plain radiography remains the primary imaging modality for DCF. The standard AP shoulder view supplemented by the Zanca view (10°–15° cephalad tilt, 50% reduced penetration) provides optimal visualization of the acromioclavicular (AC) joint and distal clavicle [16]. The axillary lateral view is essential to assess posterior displacement. Bilateral comparative views enable measurement of the CC distance (CCD); a contralateral difference of ≥5 mm or absolute CCD ≥15 mm suggests CC ligament disruption [16].

Computed tomography (CT) provides superior delin-




| | |
|---|---|
| Type I-stable | Nondisplaced or minimally displaced (<5 mm) regardless of location |
| Type II-unstable | Displaced (≥5 mm) |
| IIA | Fracture medial to the CC ligaments: conoid and trapezoid intact |
| IIB | Fracture medial to the CC ligaments: conoid torn, trapezoid intact |
| IIC | Fracture lateral to the CC ligaments: conoid and trapezoid torn |
| IID | Comminuted fracture: CC ligaments attached to inferior ligament |

**Fig. 1.** Cho classification system for distal clavicle fractures. Type I fractures are stable, nondisplaced or minimally displaced fractures (<5 mm), regardless of location. Type II fractures are unstable, displaced fractures (≥5 mm): type IIA, fracture medial to the coracoclavicular (CC) ligaments with intact conoid and trapezoid ligaments (TLs); type IIB, fracture medial to the CC ligaments with a torn conoid ligament and intact TL; type IIC, fracture lateral to the CC ligaments with torn conoid and TLs; and type IID, comminuted fracture with the CC ligaments attached to the inferior fragment. Reprinted from Cho et al. [15] according to the Elsevier user license.

eation of fracture line morphology, comminution extent, fragment number, and intra-articular involvement compared with plain radiography—information directly relevant to fixation planning when the distal fragment is small or the fracture pattern is complex [17]. A critical limitation of existing classification systems is their exclusive focus on the coronal plane, which systematically underestimates the three-dimensional (3D) complexity of DCFs. Liu et al. [17] applied 3D fracture mapping to 81 consecutive DCFs—the largest such series reported to date—using CT-based digital reconstruction and virtual repositioning to quantify multiplanar displacement. Key findings included: 92.59% of cases showed posterior displacement (mean, 6.30 mm) and posterior angulation (mean, 9.24°); 75.31% exhibited superior displacement (mean, 5.10 mm); and 91.36% demonstrated shortening at the fracture site (mean, 3.93 mm). Fracture lines were predominantly concentrated in the distal one-third of the clavicle, with highest density at the acromion end. The study identified posterior displacement and posterior angulation as the two key biomechanical predictors of therapeutic failure, consistent with the high nonunion rate in conservatively managed Neer type IIB fractures [17]. These findings demonstrate that standard radiographic classification may miss clinically consequential sagittal-plane and horizontal instability. CT should be considered when plain radiographic classification is uncertain or horizontal displacement cannot be confidently excluded (Fig. 2) [17].

MRI is the only modality capable of directly visualizing CC ligament integrity and is uniquely valuable when fracture stability classification is uncertain on radiograph. A prospective study demonstrated that MRI reclassified 8.5% of cases initially typed on plain radiographs, with treatment changes in 5%—predominantly upgrading stable fractures to operative indications due to occult CL rupture [14]. MRI additionally identifies concurrent soft tissue injuries including rotator cuff tears and AC capsular disruption. Selective use is recommended when the Neer IIA/IIB or Cho IIA/IIB distinction cannot be confidently established on radiograph and the clinical consequence of misclassification is high (Fig. 3).

Based on current evidence, the following stepwise approach is recommended: (1) bilateral AP and Zanca views with CCD measurement as the initial standard; (2) axillary lateral view to assess posterior displacement in all cases; (3) CT when comminution, fragment size, or sagittal/horizontal displacement cannot be assessed on standard views; (4) MRI when CC ligament integrity cannot be determined radiographically and the stability classification would change management [14,17].




**Fig. 2.** Computed tomography (CT) demonstrating horizontal displacement of a distal clavicle fracture that is not appreciable on standard plain radiographs. (A) Plain radiograph, (B) two-dimensional CT, and (C) three-dimensional CT.


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## Conservative treatment

Conservative management remains the standard of care for stable DCFs—Neer type I and III, or Cho type I—where the CC ligament complex is intact and displacement is minimal (<5 mm) (Fig. 4).

For unstable displaced fractures (Neer type II, Cho type II), conservative treatment may be appropriate in elderly or low-demand patients, those with significant medical comorbidities precluding surgery, or patients who explicitly prefer to avoid operative intervention after informed counseling [9,18]. A simple arm sling is the preferred immobilization device and has largely supplanted the figure-of-eight bandage, which confers no demonstrated advantage in union rate or functional outcome and is associated with neurovascular complications and patient discomfort [19].

The systematic review by Thurston et al. [9]—encompassing 779 patients across 11 studies—reported an overall union rate of 63.2% (range, 22.2%–94.4%) with conservative treatment, compared with 96.3% (range, 87.9%–100%) in operatively managed cohorts. Despite this, none of the seven comparative studies demonstrated any statistically significant difference in patient-reported outcomes. Mean Constant-Murley scores were 91.8 (nonoperative) versus 87.4 (operative), and mean Disabilities of the Arm, Shoulder, and Hand (DASH) scores were 7.8 versus 6.4, respectively [9]. The multicenter study by Hall et al. [18], conducted across seven Canadian level I trauma centers, randomized 57 patients with completely displaced Neer type II fractures to operative plate fixation or conservative sling management. At 1 year, there was no significant difference in DASH scores (operative 6.7 vs. nonoperative 10.8, P=0.31) or Constant-Murley scores (89.9 vs. 90.0, P=0.88). Operative management achieved a significantly higher union rate at 12 months (95% vs. 64%, P=0.02) and the surgical group showed earlier return to sports at 6 months (78% vs. 44%, P=0.015) [18].

The overall complication rate in nonoperatively managed displaced DCF was 45.1%, with nonunion accounting for 31.3%, CC ligament calcification for 7.4%, AC joint ar-

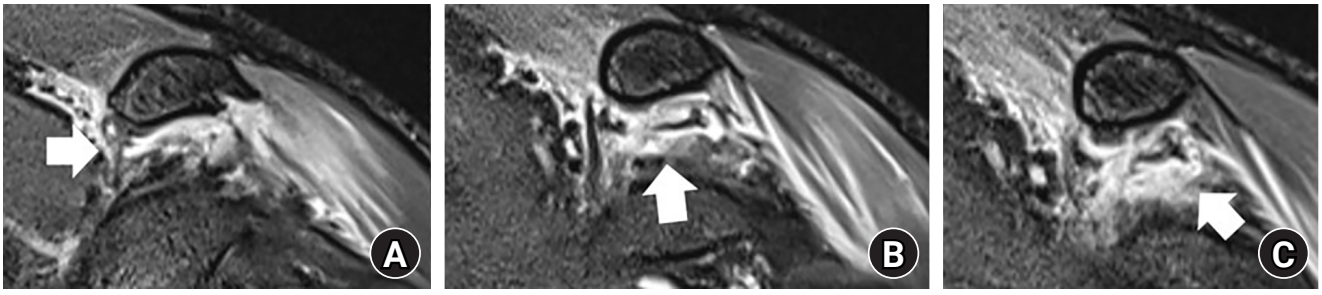



**Fig. 3.** (A–C) Magnetic resonance imaging demonstrating direct visualization of coracoclavicular ligament disruption (arrow), which cannot be reliably assessed on plain radiographs alone.

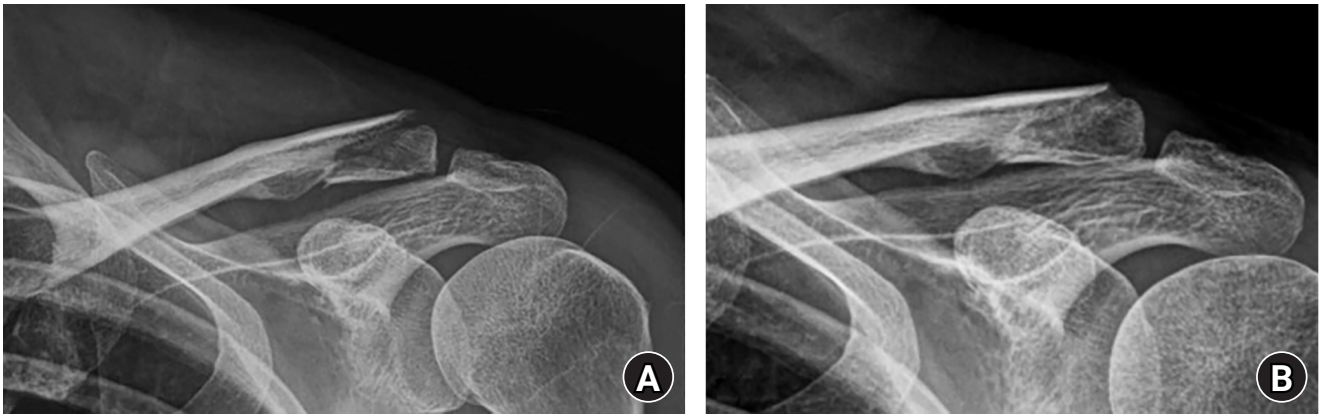



**Fig. 4.** (A) A 53-year-old female patient with a minimally displaced distal clavicle fracture (displacement <5 mm; Neer type I, Cho type I) managed conservatively. (B) Radiographic union confirmed at 5 months of follow-up.

throsis for 1.6%, and impingement for 1.6% [9]. Only 11.1% of nonoperatively managed patients required delayed surgery, predominantly for symptomatic nonunion (88.1% of delayed surgical cases) [9].

## Surgical treatment

Operative treatment consistently achieves higher union rates and earlier functional recovery at 6 months, but 1-year functional outcomes are equivalent to conservative management across all available comparative studies [8,9]. Operative fixation is recommended for unstable DCF—primarily Neer type II and V—in which disruption of the CC ligament complex produces deforming forces that preclude reliable conservative healing. Despite decades of surgical experience, no single technique has emerged as the gold standard, and fixation method selection remains guided by fracture morphology, fragment size, and surgeon experience [8,9,20]. The three dominant operative strategies are (1) plate osteosynthesis—hook plate or anatomic locking plate; (2) CC stabilization techniques; and (3) arthroscopically assisted fixation.

### Plate osteosynthesis: hook plate or anatomic locking plate

The clavicular hook plate achieves reduction by spanning the AC joint with a subacromial hook, bypassing the need for direct fixation of the small distal fragment and making it broadly applicable across fracture subtypes—including severely comminuted patterns and those with very small lateral fragments [20,21]. Union rates are consistently high (95%–98%) across comparative series and meta-analyses [22,23]. However, the subacromial hook creates an obligatory mechanical interaction with the acromion that produces well-documented implant-specific complications: subacromial impingement, acromial osteolysis (reported in up to 11.3% of cases), rotator cuff irritation, and AC joint arthrosis [20,24,25]. A systematic review and meta-analysis by Malik et al. [20] comparing 1,261 patients found that hook plate fixation carried a significantly higher overall complication rate (32.7%) than superior locking plate fixation (12.7%), with an odds ratio of 6.3. Furthermore, hook plate removal is required in the vast majority of patients after fracture union: a cost-effectiveness analysis reported a 92.5% mean probability of hook plate removal versus only 1.3% for suture-button constructs [26], effectively rendering second surgery obligatory. In the randomized controlled trial by Hall et al. [18], 71% of hook plate recipients underwent implant removal versus 18% of locking plate patients. A long-term single-center series of 53 hook plate patients confirmed a 20.8% complication rate and 18.9% revision rate at mean 6.2-year follow-up, with mean Constant-Murley score of 80.9 [25].

Anatomic precontoured distal clavicle locking plates provide multidirectional angular stability through polyaxial locking screws in the distal fragment, avoiding subacromial contact and the need for planned hardware removal. The meta-analysis by Elrih and Quinlan [22] showed that distal locking plates produced a trend toward better Constant-Murley scores (P=0.06) and significantly fewer complications compared with hook plates (P<0.0001). The meta-analysis study by Uittenbogaard et al. [8] of 2,284 patients across 59 studies found significantly lower Constant-Murley scores with hook plates than with CC fixation, and higher Constant-Murley scores when supplemental CC fixation was added to a locking plate. The primary limitation of anatomic locking plates is the requirement for an adequate distal fragment accommodating at least three locking screws [27]. Two retrospective comparative studies reported that locking plate fixation augmented with CC suture-button [28] or suture-anchor [29] fixation achieved higher Constant-Murley scores (94.6 vs. 90.1, P<0.05 [29]) and shorter union time than plate alone in Neer type IIB fractures, with fewer complications in one study [28]. A meta-analysis confirmed that locking plate plus TightRope augmentation yielded superior Constant-Murley scores (mean difference, 4.4), faster union (-2.2 weeks), lower visual analog scale pain, and fewer complications (odds ratio, 0.38) versus plate fixation alone [30].

### CC stabilization techniques

CC stabilization techniques restore vertical stability of the medial fragment by reducing it to the coracoid, thereby replicating the disrupted CC ligament complex without requiring direct fixation of the lateral fragment. Available constructs include cortical suture-button devices, CC screws, suture anchors, synthetic ligament tape, and subcoracoid cerclage. These techniques are particularly suited to fractures in which the distal fragment is too small or comminuted for plate fixation (Cho IIB, IIC), as the medial


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shaft is reduced directly to the coracoid without load transfer through the lateral fragment [31,32].

Open CC ligament reconstruction (CCLR) has demonstrated excellent results in terms of union and shoulder function. The systematic review by Malik et al. [33] dedicated specifically to open CCLR for displaced DCF confirmed that this approach is a reliable treatment with excellent union rates and good-to-excellent Constant-Murley scores, with a low complication rate. The network meta-analysis by Xu et al. [31] comparing seven fixation methods across 41 studies and 1,969 patients found that the combined construct of locking plate plus CC fixation ranked highest for both functional outcome and total complications. The earlier meta-analysis study by Boonard et al. [32] similarly identified CC fixation as the preferred technique in terms of shoulder function and complication reduction. A dedicated systematic review of CC fixation for Neer IIB (Cho IIB) and extralateral (Cho IIC) fractures (21 studies, 421 patients) confirmed very good-to-excellent clinical results with a major complication rate of only 2.6% and minor complication rate of 12.8% [34].

However, CC stabilization does carry specific limitations. The indirect nature of fracture reduction means that soft tissue interposition may persist at the fracture site, which may partly account for the moderately higher nonunion rates (approximately 5%–9%) compared with direct plating techniques [21,31]. CC ossification is a well-recognized minor complication occurring in approximately 10%–15% of cases but is typically asymptomatic and does not affect functional outcomes. Coracoid-based fixation carries inherent risk of iatrogenic coracoid fracture or cortical breach requiring technique conversion, documented in approximately 5.7% of arthroscopically treated cases, and neurovascular risk from coracoid exposure, though serious vascular injury is rarely reported [21,35]. When the distal fragment is too small, supplementary fixation with mini-fragment plates or suture anchors can be combined with the CC fixation plate to enhance structural stability (Fig. 5).

### Arthroscopic and arthroscopically assisted fixation

Arthroscopic or arthroscopically assisted fixation has emerged as a technically refined minimally invasive strategy, combining CC stabilization with the additional advantages of direct coracoid visualization for precise implant positioning, smaller incisions, reduced soft tissue stripping of the clavicle, and the ability to diagnose and simultaneously treat concomitant shoulder pathology, with 44% of the reported concomitant injuries considered addressable arthroscopically during the index procedure [35]. The predominant technique employs a cortical suture-button CC construct (97% of 226 fractures in a systematic review [35]) passed through the subacromial space under arthroscopic visualization.

The systematic review by Yagnik et al. [35]—the first dedicated exclusively to arthroscopic fixation of unstable DCF—analyzed 15 studies comprising 226 fractures. Bony union was achieved in 94.1%, and 97.7% of fractures resulted in bony union or asymptomatic nonunion. The pooled mean Constant-Murley score was 93.06 (95% CI, 91.48–94.64), consistent with good-to-excellent function. The overall complication rate was 27.4%; however, major complications (nonunion, construct failure, infection requiring reoperation, coracoid breach requiring technique conversion) occurred in only 11.9% of cases, and just 6% of all treated fractures required reoperation for hardware-related issues. A separate systematic review by Malik et al. [36] focusing specifically on arthroscopically assisted CCLR found that while shoulder function was good-to-excellent, union rates could be as low as 70% and complication rates

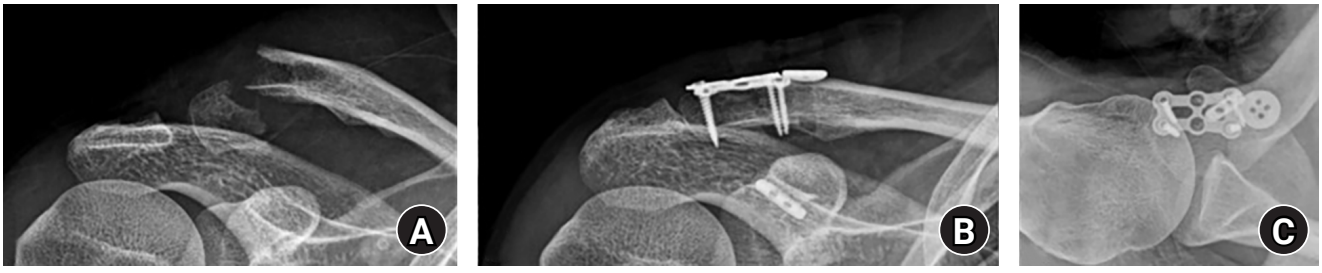



**Fig. 5.** (A) A 27-year-old female patient with an unstable distal clavicle fracture (Cho type IIC). (B, C) Surgical fixation was performed using coracoclavicular stabilization with a mini-fragment plate, achieving anatomic reduction and stable fixation.

as high as 28.6% with this specific technique—highlighting that arthroscopically assisted CCLR carries a higher nonunion risk than open CCLR or direct plating.

Additional limitations of arthroscopic fixation include technical demand, longer operative time, greater cost, and reduced applicability to highly comminuted or long oblique fractures where direct fracture site management is essential. Comparative studies between arthroscopic cortical button and hook plate fixation have found similar union rates and functional outcomes, but significantly lower reoperation burden with the arthroscopic approach [35-37].

### Technique selection and decision-making: a fracture-based approach

Technique selection is guided by two interacting factors: fracture morphology and surgeon experience. For fractures with an adequate distal fragment (Neer IIA/Cho IIA), anatomic locking plate fixation—augmented with CC suture-button when possible—provides direct, stable fixation with low complication rates and avoids the subacromial complications inherent to hook plates [28,30]. For fractures with CL disruption and small or comminuted distal fragments (Neer IIB, Cho IIB/IIC), dedicated CC stabilization—performed open or arthroscopically depending on surgeon experience—may be preferred [31,33,34]. For Cho IID fractures, locking plate fixation is recommended per the original classification when adequate distal fragment purchase is achievable; however, hook plate fixation remains a valid salvage procedure in cases of severe comminution where distal fragment purchase is insufficient (Neer V/Cho IID), with the understanding that planned implant removal will be required [21,23,38]. Regardless of technique, the decision-making process should incorporate shared discussion with the patient regarding union risk, reoperation probability, and expected recovery timeline, recognizing that 1-year functional outcomes remain equivalent across treatment strategies (Table 1).

## Future directions

Several important questions in the management of DCFs remain unanswered. The optimal indications for CC augmentation and the comparative effectiveness of open versus arthroscopic CC stabilization within specific fracture subtypes have yet to be established through prospective randomized trials. As minimally invasive techniques continue to evolve alongside advances in implant design, the applicability of arthroscopic fixation is likely to expand. Advances in musculoskeletal imaging, particularly high-resolution MRI, may further refine operative indications by enabling more precise preoperative assessment of CC ligament integrity, potentially shifting the threshold for surgical intervention in borderline cases. Future studies should prioritize direct comparisons of operative strategies within defined fracture subtypes and standardized use of both the Neer and Cho classification systems to improve evidence synthesis.

**Table 1.** Comparison of major fixation techniques for unstable distal clavicle fractures [8,20-36]

| Variable | Hook plate | Anatomic locking plate (±CC augmentation) | CC stabilization (open or arthroscopic) |
|---|---|---|---|
| Indication | Neer V / Cho IID fractures; severe comminution; very small distal fragment | Neer IIA / Cho IIA fractures; adequate distal fragment (≥3 screws) | Neer IIB / Cho IIB/IIC fractures; small or comminuted distal fragment |
| Advantage | Broadly applicable; high union rate; no need for distal fragment purchase | Direct fixation; no subacromial contact; planned hardware removal not required | No distal fragment required; low major complication rate; concomitant shoulder pathology addressable (arthroscopic) |
| Limitation | Planned removal obligatory; subacromial impingement; restricted ROM during healing | Requires adequate distal fragment; limited applicability in severe comminution | Indirect fracture reduction; technically demanding; coracoid exposure risk |
| Union rate | 95%–98% | 95%–98% | 70%–98% |
| Complication rate | Overall, 32.7%; acromial osteolysis, 11.3% | Overall, 12.7% | 0%–28.6% |
| Reoperation | ~92.5% (planned implant removal) | ~18% (implant removal) | 6%–8% (hardware-related) |

CC, coracoclavicular; ROM, range of motion.


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## Conclusions

DCFs remain challenging due to the critical role of CC ligament integrity in determining stability, the limited reliability of plain-radiograph classification, and the wide variability in distal fragment size that complicates fixation planning. For unstable fractures, operative and conservative management yield equivalent 1-year functional outcomes, and treatment decisions should be individualized through shared decision-making. When surgery is indicated, technique is generally guided by fracture morphology and surgeon experience—locking plate with or without CC augmentation for Neer IIA/Cho IIA, CC stabilization for Neer IIB (Cho IIB/IIC), and hook plate as a salvage construct for Neer V/Cho IID. CT should be selectively considered when standard radiographs fail to adequately characterize fracture morphology, comminution, or multiplanar displacement.

## Article Information

### Author contributions

Conceptualization: DHK, CHC. Investigation: HJS, BCC. Writing-original draft: HJS, BCC. Writing-review & editing: DHK, CHC, HJS, BCC. All authors read and approved the final manuscript.

### Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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Not applicable.

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### Supplementary materials

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# Impact of posterior wall involvement and fixation on clinical and radiographic outcomes of associated both-column acetabular fractures: a systematic review and meta-analysis

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**Background:** Posterior wall (PW) fractures are frequently associated with both-column (ABC) acetabular fractures. However, whether the presence of a PW fragment or the need for internal fixation affects prognosis remains a topic of debate. This study compared postoperative outcomes, including reduction quality and clinical results, according to the presence of an associated PW fracture and whether PW fixation was performed.

**Methods:** This systematic review and meta-analysis followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. MEDLINE, Embase, and the Cochrane Library were searched for articles published up to December 10, 2025. Comparative studies of ABC fractures were included if they evaluated the presence or absence of PW involvement or compared internal fixation with nonfixation of the PW component. Clinical and radiographic outcome data were extracted.

**Results:** Seven retrospective studies including 434 analyzable patients were included. No clear differences were found in the odds of poor reduction (odds ratio [OR], 0.91; 95% confidence interval [CI], 0.43–1.94; P=0.80), osteoarthritis (OR, 1.04; 95% CI, 0.37–2.92; P=0.94), or conversion to total hip arthroplasty (OR, 0.63; 95% CI, 0.23–1.71; P=0.36) according to the presence of a PW fragment in ABC fractures. Among ABC fractures with PW involvement, nonfixation was associated with numerically higher odds of poor reduction than fixation, although the difference was not statistically significant (OR, 1.47; 95% CI, 0.46–4.76; P=0.52). In unadjusted comparisons of non-randomized cohorts, PW fixation was associated with significantly longer operative time (mean difference [MD], 70.38 min; 95% CI, 24.46–116.29; P=0.003) and greater intraoperative blood loss (MD, 351.36 mL; 95% CI, 244.97–457.74; P<0.00001). The final modified Merle d'Aubigné-Postel score did not differ significantly between the fixation and nonfixation groups (MD, 0.58 points; 95% CI, –0.57 to 1.74; P=0.32).

**Conclusions:** Current evidence does not clearly support routine fixation of all PW fragments. In unadjusted comparisons of non-randomized cohorts, patients who underwent PW fixation had longer operative time and greater blood loss. These differences cannot be attributed to fixation itself because of confounding by indication and the frequent use of an additional posterior approach. Selective fixation based on residual displacement, joint congruency, and hip stability appears reasonable, although the certainty of evidence remains limited.

**Level of evidence:** Not applicable.

**Keywords:** Acetabulum; Internal fracture fixation; Treatment outcome; Postoperative complications; Systematic review

**Systematic Review**

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## Introduction

### Background

Acetabular fractures, although relatively uncommon, are typically the result of high-energy trauma and frequently lead to poor functional outcomes if not appropriately managed. Since the 1960s, these injuries have been categorized using the ten fracture patterns described by Judet et al. [1]. However, establishing an accurate diagnosis and surgical plan remains challenging because of intricate anatomical structures and inherent variability in fracture patterns. Among these, associated both-column (ABC) fractures are complex lesions involving detachment of the entire articular surface from the sciatic buttress. Although a posterior wall (PW) fragment is observed in approximately 35% of ABC cases, this specific combination is notably absent from the original Letournel classification [2].

The presence of a PW component in ABC fractures raises significant clinical concerns regarding joint stability, given its primary role as a weight-bearing surface [3]. Although surgical stabilization of the PW is conventionally recommended to restore hip integrity, emerging evidence suggests that PW fragments with ABC patterns differ etiologically from isolated PW fractures. Although isolated PW fractures often result from direct posterior shear forces during dislocation, PW fragments in ABC fractures are frequently caused by an anterior pull-type or avulsion mechanism through an intact capsulolabral complex during central dislocation [4]. Due to this distinct injury mechanism, the optimal management of the associated PW component remains a subject of significant debate. It has been proposed that these fragments may remain stable after column reconstruction alone and can be ignored, without compromising functional outcomes [5]. However, PW fixation using plates and screws through a sequential Kocher-Langenbeck approach has also been suggested to ensure anatomical restoration [6]. Furthermore, other studies have demonstrated the feasibility of lag screw fixation alone through the lateral extension of a single anterior approach, thereby avoiding the morbidity of a secondary posterior incision [7].

Although several clinical studies have investigated the relationship between PW involvement and outcomes in ABC fractures, these reports are often limited by small sample sizes, leading to inconsistent conclusions. To our knowledge, no systematic review has synthesized these findings to provide consolidated evidence on PW involvement and ABC fracture outcomes. Therefore, we integrated data from multiple institutions to enhance the statistical power of the analysis and overcome the limitations of single-center studies.

### Objectives

The purpose of this study was to evaluate the impact of PW involvement on the clinical prognosis and to determine whether PW fixation is necessary for optimal outcomes in ABC fracture patterns.

## Methods

### Study design

The overall methodology of this study was based on the Cochrane Handbook for Systematic Reviews of Interventions [8]. Furthermore, this systematic review and meta-analysis was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [9].

### Ethics statement

This is a literature-based study; therefore, neither institutional review board approval nor informed consent was required.

### Eligibility criteria

The selected studies directly compared (1) the clinical outcomes of ABC fractures according to the presence or absence of a concomitant PW fragment, and (2) the surgical results between fixation and nonfixation of the PW component when present. The exclusion criteria were nonclinical or secondary research, including biomechanical and cadaveric studies, review articles, meta-analyses, and expert opinions. Technical notes, letters to the editor, conference abstracts, and case reports were also excluded. Additionally, duplicate publications that used identical patient cohorts or multiple publications that should have been reported as a single study were removed.

### Information sources

We searched the MEDLINE, Embase, and Cochrane Library databases to identify comparative studies that eval-

uated the surgical outcomes of ABC fractures with concurrent PW fragments.

### Search strategy

A systematic search was conducted for articles published from inception until December 10, 2025, using an a priori search strategy. The search terms included synonyms and related terms for ABC and PW as follows: ("both columns" OR "two columns") AND ("posterior wall") AND ("acetabular fracture"). Relevant studies were identified through a systematic search of the databases, with the scope limited to articles published in English. In addition, the reference lists of the retrieved studies were manually reviewed to ensure a comprehensive search.

### Selection process

Study titles and abstracts were independently reviewed by two fellowship-trained board-certified orthopedic surgeons specializing in hip and pelvic trauma. In cases where the abstract provided inadequate details, a comprehensive full-text assessment was conducted. To quantify the level of agreement between reviewers, the κ-value was calculated for each phase of the study selection. Agreement levels were categorized as follows: perfect (κ=1), almost perfect (0.8≤κ<1.0), substantial (0.6≤κ<0.8), moderate (0.4≤κ<0.6), fair (0.2≤κ<0.4), and slight (κ<0.2). Disagreements were resolved by mutual consensus or, if necessary, by a third independent board-certified orthopedic surgeon.

### Data collection process

For the qualitative synthesis, we performed a systematic extraction and comprehensive review of essential parameters from the recruited studies. Data extraction was performed independently by two reviewers and discrepancies were resolved through discussion.

### Data items

We extracted the following data: study design, number of patients in each group, mean patient age, sex distribution, follow-up duration, indications for PW fixation, whether stability was assessed after column fixation, surgical approach, operation time, blood loss, overall acetabular/articular reduction quality assessed according to the Matta criteria, as reported in each original study [10], functional outcomes, presence of osteoarthritis, conversion to total hip arthroplasty (THA), and surgical site infection (SSI). Because the grading systems and thresholds varied across studies, osteoarthritis and reduction quality were dichotomized according to the definitions reported in each original study. Accordingly, the pooled estimates were interpreted cautiously because the underlying definitions were not fully equivalent. Given the heterogeneity in the surgical indications for PW fixation across the included studies, we specifically analyzed the clinical criteria for fixation and the methodology of intraoperative stability assessment following column reconstruction.

### Study risk of bias assessment

The methodological quality and risk of bias of the included studies were assessed using the Risk of Bias in Non-randomized Studies of Interventions (ROBINS-I) tool [11]. This tool evaluates seven domains: bias due to confounding factors, bias in the selection of participants, bias in the classification of interventions, bias due to deviations from intended interventions, bias due to missing data, bias in the measurement of outcomes, and bias in the selection of reported results. Each domain was rated as follows: low, moderate, serious, critical, or no information.

### Effect measures

Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated for dichotomous outcomes, whereas mean differences (MDs) with 95% CIs were used for continuous outcomes. The $I^2$ statistic was used to assess study heterogeneity, where values of 25%, 50%, and 75% represent low, moderate, and high levels of inconsistency, respectively.

### Synthesis methods

Comparative analyses were stratified into two primary subgroups: (1) presence or absence of PW fracture and (2) fixation or nonfixation of the PW fragment. This meta-analysis focused on variables reported in at least two studies. We included data on operation time, blood loss, reduction quality, osteoarthritis, THA conversion, and functional outcome. For the pooled reduction-quality analyses, only overall acetabular/articular reduction was included; PW-specific displacement measurements were not pooled. Individual study findings, pooled effect sizes, and overall estimates were visualized using forest plots. Statistical significance was defined as P<0.05. The data were synthesized


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using random-effects models because clinical and methodological heterogeneity across studies was anticipated, including differences in indications for PW fixation, surgical approaches, outcome assessment, and perioperative management [12]. Between-study variance ($\tau^2$) was estimated using the DerSimonian-Laird method. Fixed-effect analyses using the same eligible studies were performed as sensitivity analyses. All computational analyses were conducted using Review Manager (RevMan v.5.3; The Cochrane Collaboration).

### Reporting bias assessment

Following Cochrane recommendations, publication bias was not formally assessed because the total number of included studies was less than ten [13].

## Results

### Study selection

The study selection and identification procedures are shown in Fig. 1. An initial systematic search of electronic databases yielded 149 records (MEDLINE, 70; Embase, 75; and Cochrane, 4). After removing 69 duplicates, 80 unique citations were retained for further assessment. Although a manual search was conducted to identify additional relevant literature, no further studies were found (n=0). During the initial screening of titles and abstracts, 66 records were excluded. The remaining 14 articles underwent comprehensive full-text eligibility assessment. Of these, seven were excluded for the following reasons: lack of relevance to the specific field of interest (n=3) and insufficient data to allow for a comparative analysis (n=4). Seven studies met the inclusion criteria and were incorporated into both the qualitative synthesis and quantitative meta-analysis. Reviewer consistency was evaluated using κ statistics. The levels of agreement were substantial during the title and abstract screening phases (κ=0.720 and κ=0.777, respectively). Furthermore, the reviewers achieved perfect consensus during the full-text review stage (κ=1.0).

### Study characteristics

All seven studies were retrospective cohort studies [3,5-7,14-16]. Among the included studies, four compared outcomes based on the presence or absence of a PW fragment [3,5,7,15]. Two studies focused specifically on patients with PW fragments and compared those who received fixation to those who did not [14,16]. Additionally, one study conducted a three-arm comparative analysis of ABC fractures

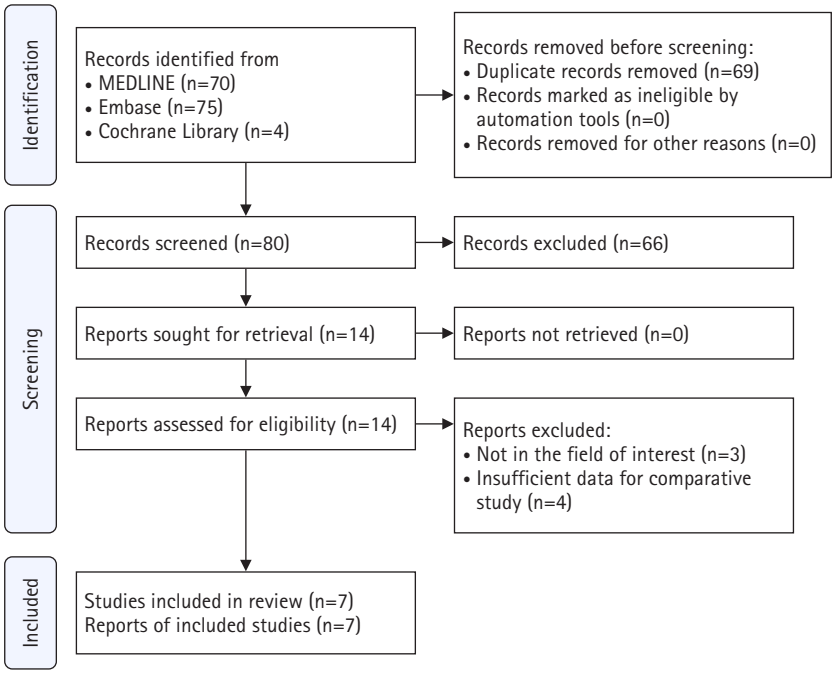



**Fig. 1.** Flow diagram of the study selection process according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. No additional records were identified through manual searches of the reference lists of the retrieved studies.

without PW, ABC fractures with fixed PW, and ABC fractures with non-fixed PW [6]. Seven studies contributed comparative data on 434 patients: 211 without PW involvement, 126 with PW involvement treated with fixation, and 97 with PW involvement managed without fixation. No patient-cohort overlap was identified among the included studies based on the reported institutions, enrollment periods, author groups, and cohort characteristics. The mean patient age ranged from 41.7–62.7 years. The proportion of female patients ranged from 18.4%–40.3%. The follow-up periods ranged from 12–54 months (Table 1) [3,5-7,14-16].

Regarding the surgical approaches for ABC fractures, five studies used either the ilioinguinal or Stoppa approaches [5,7,14-16]. One study utilized either the ilioinguinal or extended iliofemoral approach [3], whereas another study used the supra-ilioinguinal approach [6]. Of the approaches used for open reduction and PW fixation, the Kocher-Langenbeck approach was the predominant choice [3,5,6,14,16]. The operative time ranged from 163–241 minutes in the absence of PW fixation and from 197–271 minutes in cases where PW fixation was performed. The estimated intraoperative blood loss ranged from 703–889 mL in the absence of PW fixation, and varied from 957–1,177 mL when PW fixation was performed. The rate of suboptimal reduction varied across the individual study cohorts (Table 2) [3,5-7,14-16].

Heterogeneity in functional outcomes was observed across the included studies. Five studies [6,7,14-16] utilized the Merle d'Aubigné-Postel (MAP) score as the primary assessment tool [17], whereas one study employed the Harris Hip Score [18]. The mean MAP scores reported in three studies ranged from 15.4–16.2. In two studies reporting categorical functional outcomes, the proportion of patients achieving excellent or good results ranged from 78.3%–88.0%, according to the criteria used in the original studies. Four studies reported the presence of osteoarthritis during follow-up. The incidence of post-traumatic osteoarthritis reported in the included studies ranged from 2.9%–20.7%. The conversion rate to THA ranged from 0%–22.2% in patients who underwent PW fixation. The incidence of SSI ranged from 0% in patients who did not undergo PW fixation to 8.7% in those who underwent PW fixation (Table 3) [3,5-7,14-16].

## Risk of bias in studies

The risk of bias assessment using ROBINS-I showed an overall moderate risk of bias in five studies and a serious risk in two studies [6,14]. The principal concern in the two

**Table 1.** Summary of patient demographic data from the included studies

| Study | Study design | Number of patients | | | Mean age (yr) | | | Female sex | | | Follow-up (mo)[b] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PW– | PW+Fix+ | PW+Fix– | PW– | PW+Fix+ | PW+Fix– | PW– | PW+Fix+ | PW+Fix– | |
| Wang et al. [7] (2017) | RCS | 64 | 35 | NA | 48.3±11.8 | 44.4±12.5 | NA | 17 | 10 | NA | 44.7±18.5 |
| Min et al. [15] (2018) | RCS | 25 | 15 | 2 | 46.2 | 45.7[c] | | 8 | 4[c] | | 54.0 |
| Shin et al. [5] (2020) | RCS | 29 | 3 | 17 | 51.1±23.3 | 48.1±23.6[c] | | 5 | 4[c] | | 36.6±18.5 |
| Chen et al.a) [14] (2021) | RCS | 39 | 11 | 29 | 50.9±18.8 | 51.2±16.8 | 62.7±16.7 | 12 | 1 | 7 | 49.9±39.2 |
| Tian et al. [16] (2022) | RCS | NA | 23 | 26 | NA | 45.5±11.2 | 46.1±11.8 | NA | 5 | 5 | 27.1±6.9 |
| Reahl et al. [3] (2023) | RCS | 26 | 18 | NA | 48.5±16.7 | 51.4±12.0 | NA | 6 | 4 | NA | 43.0 |
| Wan et al. [6] (2023) | RCS | 28 | 21 | 23 | 44.8±14.1 | 41.7±12.3 | 42.5±13.1 | 12 | 8 | 9 | Min 12 mo |

PW, posterior wall; Fix, fixation; PW–, associated both-column fractures without posterior wall involvement; PW+Fix+, associated both-column fractures with posterior wall involvement treated with fixation; PW+Fix–, associated both-column fractures with posterior wall involvement treated without fixation; RCS, retrospective cohort study; NA, not applicable; Min, minimum.

[a]Chen et al. [14] initially identified 88 patients; nine patients with insufficient follow-up were excluded, leaving 79 analyzable patients. [b]Follow-up periods are presented as mean±standard deviation when available. Studies without reported standard deviations are shown as mean values only. Wan et al. [6] reported a minimum follow-up of 12 months without a mean value. [c]For Min et al. [15] and Shin et al. [5], baseline age and sex data were reported for the combined PW-positive cohort and were not separately available according to PW fixation status.


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**Table 2.** Perioperative profile

| Study | Approach | | | Operation time (min) | | | Blood loss (mL) | | | Poor reduction | | | Assessment modality |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PW– | PW+Fix+ | PW+Fix– | PW– | PW+Fix+ | PW+Fix– | PW– | PW+Fix+ | PW+Fix– | PW– | PW+Fix+ | PW+Fix– | |
| Wang et al. [7] (2017) | Ilioinguinal | | | 241±49 | 258±60 | NA | 889±154 | 957±259 | NA | 11 | 7 | NA | X-ray |
| Min et al. [15] (2018) | Ilioinguinal | | | NR | NR | NR | NR | NR | NR | 1 | 0[c] | | X-ray & CT |
| Shin et al. [5] (2020) | Ilioinguinal | Ilioinguinal, KL | Ilioinguinal | NR | NR | NR | NR | NR | NR | 3 | 3[c] | | X-ray[a] |
| Chen et al. [14] (2021) | Ilioinguinal, Stoppa | Ilioinguinal, Stoppa, KL | Ilioinguinal, Stoppa | NR | NR | NR | NR | NR | NR | NR | 0 | 5 | X-ray[b] |
| Tian et al. [16] (2022) | NA | Stoppa, KL | Stoppa | NA | 220±73 | 175±36 | NA | 1,056±488 | 785±303 | NA | 3 | 4 | NR |
| Reahl et al. [3] (2023) | Ilioinguinal, KL, extended iliofemoral | | | 215±94 | 197±63 | NA | NR | NR | NA | NR | NR | NA | NA |
| Wan et al. [6] (2023) | Supra-ilioinguinal | Supra-ilioinguinal, KL | Supra-ilioinguinal | 163±21 | 271±33 | 179±35 | 703±143 | 1,177±211 | 804±193 | 3 | 2 | 2 | X-ray |

PW, posterior wall; Fix, fixation; PW–, associated both-column fractures without posterior wall involvement; PW+Fix+, associated both-column fractures with posterior wall involvement treated with fixation; PW+Fix–, associated both-column fractures with posterior wall involvement treated without fixation; NA, not applicable; NR, not reported; CT, computed tomography; KL, Kocher-Langenbeck.

[a]Shin et al. [5] assessed reduction quality using both postoperative radiographs and CT; radiograph-based Matta grading was used for the present analysis. [b]For Chen et al. [14], overall articular reduction according to the Matta criteria was assessed in the subset with ≥1-year follow-up (PW+Fix+, 7; PW+Fix–, 14). [c]For Min et al. [15] and Shin et al. [5], poor reduction was reported for the combined PW-positive cohort and was not available separately according to PW fixation status.

**Table 3.** Clinical outcomes

| Study | Functional outcome[a] | | | Osteoarthritis[b] | | | Conversion to THA | | | SSI | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PW– | PW+Fix+ | PW+Fix– | PW– | PW+Fix+ | PW+Fix– | PW– | PW+Fix+ | PW+Fix– | PW– | PW+Fix+ | PW+Fix– |
| Wang et al. [7] (2017) | 15.7±1.9 | 15.9±1.8 | NA | 2 | 1 | NA | 1 | 1 | NA | 1 | 2 | NA |
| Min et al. [15] (2018) | 22 | 14 | | 3 | 3 | | 3 | 3 | | 0 | 1 | |
| Shin et al. [5] (2020) | 89.0±6.6 | 90.5±6.8 | | 6 | 3 | | 2 | 1 | | 0 | 1 | |
| Chen et al. [14] (2021) | NR | 15.9±3.0 | 15.4±3.6 | NR | 1.1±0.7 | 1.3±0.9 | NR | 0 | 3 | NR | NR | NR |
| Tian et al. [16] (2022) | NA | 16.2±2.2 | 15.6±2.3 | NA | NR | NR | NA | NR | NR | NA | 2 | 0 |
| Reahl et al. [3] (2023) | NR | NR | NA | NR | NR | NA | 3 | 4 | NA | 2 | 1 | NA |
| Wan et al. [6] (2023) | 24 | 18 | 18 | NR | NR | NR | NR | NR | NR | NR | NR | NR |

THA, total hip arthroplasty; SSI, surgical site infection; PW, posterior wall; Fix, fixation; PW–, associated both-column fractures without posterior wall involvement; PW+Fix+, associated both-column fractures with posterior wall involvement treated with fixation; PW+Fix–, associated both-column fractures with posterior wall involvement treated without fixation; NA, not applicable; NR, not reported; MAP, modified Merle d'Aubigné-Postel score; HHS, Harris Hip Score.

[a]Functional outcomes are presented as mean MAP scores for Wang et al. [7], Chen et al. [14] (subset with ≥1-year follow-up: PW+Fix+, 7; PW+Fix–, 14), and Tian et al. [16]; as mean HHS values for Shin et al. [5]; and as the numbers of patients with excellent or good outcomes according to the MAP criteria for Min et al. [15] and Wan et al. [6]. [b]Wang et al. [7] used the Kellgren-Lawrence grading system. Min et al. [15] and Shin et al. [5] used Matta's radiographic grading system; Min et al. [15] reported poor outcomes, whereas Shin et al. [5] reported fair or poor outcomes. Chen et al. [14] reported mean Tonnis grades.

studies with serious risk of bias was confounding by indication, because PW fixation was determined by residual displacement or surgeon discretion without adequate adjustment for these treatment-selection factors. None of the studies was considered to have a critical risk of bias (Table 4).

### Results of individual studies

Individual study characteristics, including patient demographics, surgical approaches, operative time, and blood loss, are presented in Tables 1 and 2. Functional outcomes, osteoarthritis incidence, and conversion to THA for each study are detailed in Table 3. Forest plots (Figs. 2 and 3)

**Table 4.** Risk of bias assessment using the ROBINS-I tool

| Study | Confounding | Selection | Intervention classification | Deviation from intervention | Missing data | Measurement of outcome | Selection of reported result | Overall |
|---|---|---|---|---|---|---|---|---|
| Wang et al. [7] (2017) | Moderate | Low | Low | Low | Low | Moderate | Moderate | Moderate |
| Min et al. [15] (2018) | Moderate | Low | Low | Low | Low | Low | Moderate | Moderate |
| Shin et al. [5] (2020) | Moderate | Low | Low | Low | Low | Low | Moderate | Moderate |
| Chen et al. [14] (2021) | Serious | Moderate | Low | Low | Moderate | Moderate | Moderate | Serious |
| Tian et al. [16] (2022) | Moderate | Moderate | Low | Low | Low | Moderate | Moderate | Moderate |
| Reahl et al. [3] (2023) | Moderate | Moderate | Low | Low | Moderate | Moderate | Moderate | Moderate |
| Wan et al. [6] (2023) | Serious | Low | Low | Low | Low | Moderate | Moderate | Serious |

ROBINS-I, Risk of Bias in Non-randomized Studies of Interventions.

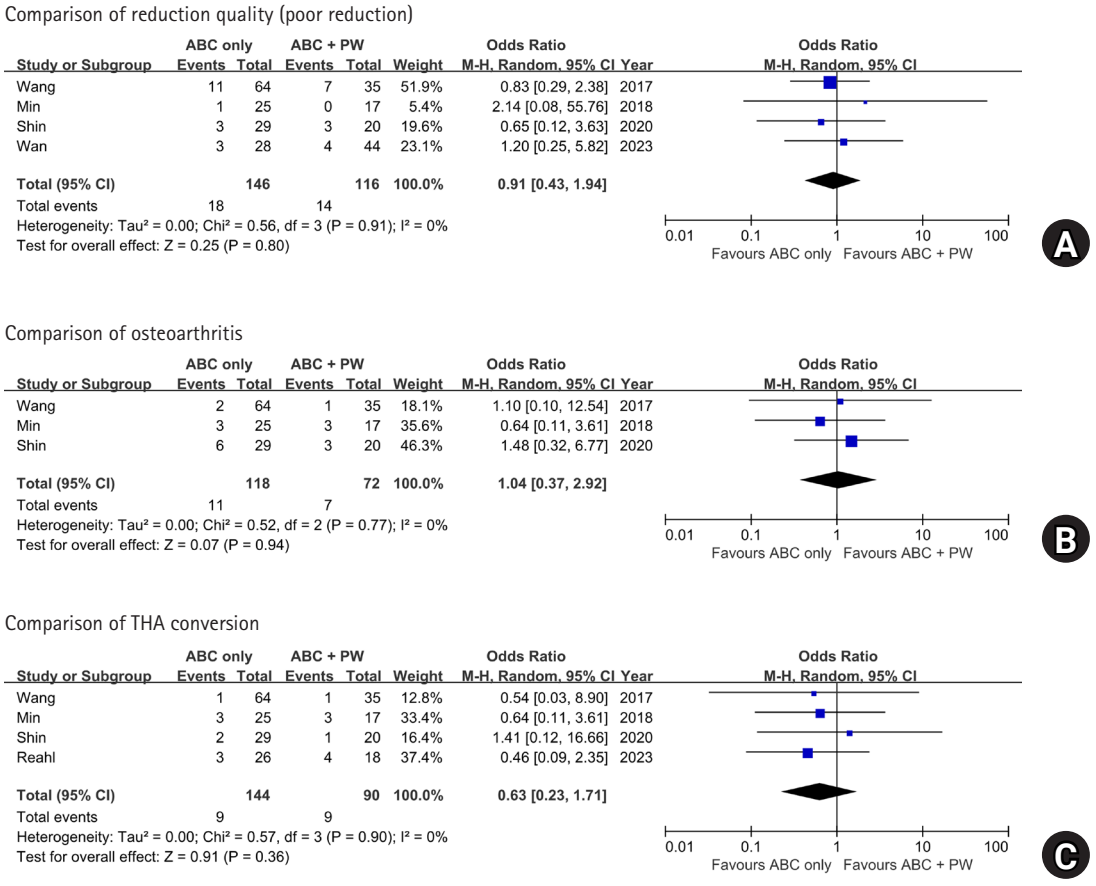



**Fig. 2.** Forest plots comparing (A) poor reduction, (B) osteoarthritis, and (C) conversion to THA according to the presence of a PW fragment. ABC, associated both-column; PW, posterior wall; M-H, Mantel-Haenszel; CI, confidence interval; THA, total hip arthroplasty.


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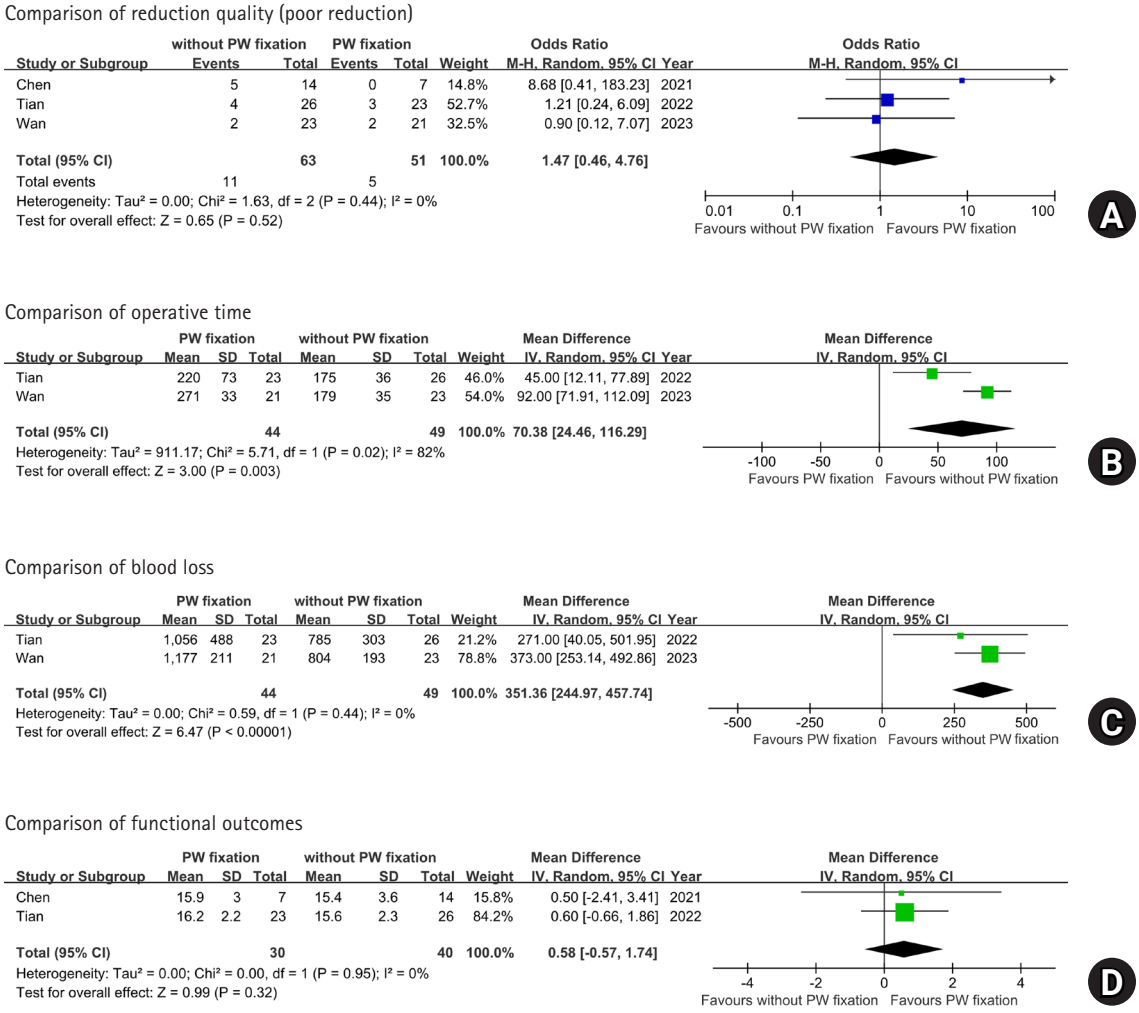



**Fig. 3.** Forest plots comparing (A) poor reduction, (B) operative time, (C) intraoperative blood loss, and (D) functional outcome according to PW fixation status. M-H, Mantel-Haenszel; CI, confidence interval; PW, posterior wall; SD, standard deviation; IV, inverse variance.

visualize the individual study effect estimates for each analyzed outcome.

## Results of syntheses

Meta-analysis results stratified by the presence of PW fragment

*Reduction quality*

Four studies compared reduction quality between patients with ABC fractures without PW involvement (n=146) and those with PW involvement (n=116) [5-7,15]. No clear difference was demonstrated in the odds of poor reduction between the two groups (OR, 0.91; 95% CI, 0.43–1.94; P=0.80; $I^2$=0%) (Fig. 2A).

*Osteoarthritis*

Three studies compared osteoarthritis between patients with ABC fractures without PW involvement (n=118) and those with PW involvement (n=72) [5,7,15]. The mean follow-up durations were 37 months in Shin et al. [5], 45 months in Wang et al. [7], and 54 months in Min et al. [15]. No clear difference was demonstrated in the odds of osteoarthritis between the two groups (OR, 1.04; 95% CI, 0.37–2.92; P=0.94; $I^2$=0%) (Fig. 2B).

*THA conversion*

Four studies compared conversion to THA between patients with ABC fractures without PW involvement (n=144) and those with PW involvement (n=90) [3,5,7,15]. The

mean follow-up durations were 43 months in Reahl et al. [3], 37 months in Shin et al. [5], 45 months in Wang et al. [7], and 54 months in Min et al. [15]. No clear difference was demonstrated in the odds of THA conversion between the two groups (OR, 0.63; 95% CI, 0.23–1.71; P=0.36; $I^2$=0%) (Fig. 2C).

Meta-analysis results according to fixation of PW fragment

*Reduction quality*

Three studies compared the reduction quality among patients with ABC fractures and PW involvement according to whether the PW fragment was fixed [6,14,16]. The pooled analysis did not demonstrate a clear difference in the odds of poor reduction between the nonfixation and fixation groups (OR, 1.47; 95% CI, 0.46–4.76; P=0.52; $I^2$=0%) (Fig. 3A).

*Operation time*

Two studies directly compared operative time between PW fixation and nonfixation among patients with PW involvement [6,16]. The PW fixation and nonfixation groups included 44 and 49 patients, respectively. The pooled analysis showed PW fixation was associated with a longer operative time than nonfixation (MD, 70.38 min; 95% CI, 24.46–116.29; P=0.003). Substantial between-study heterogeneity was observed ($I^2$=82%) (Fig. 3B).

*Blood loss*

Two studies directly compared intraoperative blood loss between PW fixation and nonfixation among patients with PW involvement [6,16]. The PW fixation and nonfixation groups included 44 and 49 patients, respectively. The pooled analysis showed greater intraoperative blood loss in the PW fixation group than in the nonfixation group (MD, 351.36 mL; 95% CI, 244.97–457.74; P<0.00001; $I^2$=0%) (Fig. 3C).

*Functional outcome*

Two studies involving 70 patients directly compared final functional outcomes using the modified MAP score between PW fixation and nonfixation groups [14,16]. The PW fixation and nonfixation groups included 30 and 40 patients, respectively. The pooled analysis did not demonstrate a clear difference in the final MAP score between the two groups (MD, 0.58 points; 95% CI, −0.57 to 1.74; P=0.32; $I^2$=0%) (Fig. 3D).

*Sensitivity analysis*

Fixed-effect sensitivity analyses using the same eligible studies yielded results that were materially consistent with the primary random-effects analyses, without changes in the direction or statistical significance of the pooled estimates (Supplementary Figs. 1, 2).

Indications for fixation and stability assessment

The criteria for internal fixation of the PW fragment and methods used to assess hip stability varied among the included studies (Table 5). Some studies applied fragment size or residual displacement as key criteria for fixation, whereas others relied on the surgeon's discretion, intraoperative stability assessment, treatment period, or preoperative virtual simulation. Min et al. [15] used a 20% PW involvement threshold combined with an assessment of joint stability, whereas Shin et al. [5] emphasized residual incongruity, gross instability on stress examination, and attachment of the fragment to the labrocapsular complex. In addition, intraoperative stability assessment following reconstruction of the main columns was reported by Shin et al. [5], Wang et al. [7], and Tian et al. [16], although the role of assessment differed among studies, ranging from confirmation of stability after fixation to decision-making for selective nonfixation. Wan et al. [6] used computer-assisted virtual reduction and selected a posterior approach when >3 mm of displacement remained after simulated reduction of the main columns. These differences highlight the absence of standardized indications for PW fixation in patients with ABC fractures.

### Reporting biases

Publication bias assessment was not formally conducted due to fewer than ten included studies, limiting formal evaluation of potential reporting bias. However, the retrospective design of all studies and heterogeneity in outcome reporting across studies potentially introduces selective reporting bias, though the direction and magnitude of such bias remain uncertain.

## Discussion

### Key results

The principal finding of this study was that no clear association was demonstrated between PW involvement and


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**Table 5.** Indications for fixation of PW

| Study | Comparisons | Indications for fixation of PW | Stability assessment after column fixation |
|---|---|---|---|
| Wang et al. [7] (2017) | PW– vs. PW+Fix+ | No specific clinical threshold (such as size or mm) was provided. | Performed (under fluoroscopy) |
| Min et al. [15] (2018) | PW– vs. PW+ | Left unfixed if <20% and the joint was stable. Fixed if the fragment represented >20% of the fracture surface on CT. | Not performed (acknowledged as limitation) |
| Shin et al. [5] (2020) | PW– vs. PW+ | Fixed if gross instability was present on stress exam, or if there was joint incongruency (step-off >2 mm or gap >3 mm), or if the fragment lacked attachment to the labrocapsular complex. | Performed (90° flexion with axial load) |
| Chen et al. [14] (2021) | PW+Fix+ vs. PW+Fix– | Performed at the surgeon's discretion. | Not performed (not routinely assessed) |
| Tian et al. [16] (2022) | PW+Fix+ vs. PW+Fix– | Treatment was based on the study period: PWs were routinely fixed in the early group (via the KL approach) but were no longer fixed in the recent group due to evolving understanding. | Performed (under anesthesia) |
| Reahl et al. [3] (2023) | PW– vs. PW+Fix+ | No specific clinical threshold (like size or mm) was provided. | Not reported |
| Wan et al. [6] (2023) | PW– vs. PW+Fix– vs. PW+Fix+ | A posterior approach was required if more than 3 mm of displacement remained in the reduced 3D model after virtual reduction of the main columns. | Not performed (relied on preoperative 3D virtual simulation) |

PW, posterior wall; Fix, fixation; PW–, associated both-column fractures without posterior wall involvement; PW+, associated both-column fractures with posterior wall involvement; PW+Fix+, associated both-column fractures with posterior wall involvement treated with fixation; PW+Fix–, associated both-column fractures with posterior wall involvement treated without fixation; CT, computed tomography; KL, Kocher-Langenbeck; 3D, three-dimensional.

inferior overall clinical or radiographic outcomes in ABC fractures. In the included studies, PW fragments were managed using different strategies; some authors adopted selective nonfixation when the fragment was considered stable after column reconstruction, whereas others performed PW fixation when residual displacement, incongruity, or instability was suspected. In analyses limited to ABC fractures with PW involvement, PW fixation was associated with a greater operative burden, including longer operative time and greater intraoperative blood loss. However, the available analyses did not demonstrate clear differences in the reported clinical and radiographic outcomes between the fixation and nonfixation groups. Among the meta-analytic results, nonfixation was associated with numerically higher odds of poor reduction than fixation, although the difference was not statistically significant (OR, 1.47; 95% CI, 0.46–4.76; P=0.52).

## Interpretation

The findings should not be interpreted as supporting either routine nonfixation or mandatory fixation of PW fragments. Rather, they suggest that the presence of a PW component itself does not necessarily worsen prognosis when it is appropriately assessed and managed. Selective fixation in the indicated cases may mitigate the potential adverse effects of unstable or incongruent PW fragments, although routine fixation may not be mandatory. Given that several of the included studies incorporated intraoperative stability testing or assessment of residual incongruity after column reconstruction, individualized management based on hip stability, fragment displacement, and joint congruency appears to be a reasonable strategy.

Heterogeneity in the indications for PW fixation is a key consideration in interpreting the present findings, as it represents both a limitation of the quantitative synthesis and an important finding of the qualitative analysis. Because PW fixation was generally selected for larger, more displaced, incongruent, or unstable fragments, the fixation groups may have included more complex injuries, potentially biasing operative and radiographic outcomes against fixation. Conversely, the younger age observed in some fixation cohorts may reflect a greater tendency to pursue PW fixation in patients for whom long-term joint preservation was considered particularly important. These baseline imbalances and treatment-selection factors limit causal interpretation of comparisons according to PW fixation sta-

tus. Previous morphological studies suggested that PW involvement in ABC fractures tends to represent a larger and more extensive posterior element injury, with transverse or oblique fracture lines present on the retroacetabular surface, rather than a typical posterior rim fracture-dislocation pattern [19,20]. In this context, reconstruction of the main ABC components may indirectly reduce or stabilize the associated PW fragment through capsulolabral tension or traction of the surrounding soft tissues [5,15,16]. This suggests that after the reduction and fixation of the main ABC components, the assessment of residual displacement, joint congruency, and intraoperative hip stability may provide a clinically meaningful indication for additional PW fixation.

In the analysis stratified by the presence of a PW fracture, clear associations with reduction quality, osteoarthritis, or conversion to THA were not demonstrated. Because the quality of reduction is a major determinant of long-term clinical and radiographic outcomes after acetabular fracture surgery, the absence of a significant difference in reduction quality may partly explain the comparable rates of osteoarthritis and THA conversion between patients with and without PW involvement [21]. However, long-term outcomes in ABC fractures may be more strongly influenced by the quality of reduction of the main acetabular columns and other established predictors of conversion to THA, such as age, increased body mass index, and dome impaction, than by the presence of a PW fragment [21,22].

In the analysis according to PW fixation status, the pooled reduction outcome reflected overall acetabular/articular reduction based on the Matta criteria, which may not be sufficiently sensitive to residual displacement confined to an unfixed PW fragment. Therefore, the present analysis may have underestimated PW-specific differences in reduction between the fixation and nonfixation groups. Nevertheless, whether improved PW reduction translates into clinically meaningful long-term benefits remains unclear because subsequent outcomes, such as osteoarthritis and THA conversion, were not reported according to PW fixation status.

This study found that operative time and intraoperative blood loss differed significantly according to the PW fixation status. This finding may be partly explained by the surgical approach used for the PW fixation. In several of the included studies, PW fixation required an additional posterior approach, most commonly the Kocher-Langenbeck approach, which may have increased operative time and blood loss due to patient repositioning, additional exposure, and greater soft-tissue dissection [5,6,14,16]. Given that the fixation of ABC fractures alone is associated with substantial intraoperative blood loss, often in the range of ~700–900 mL in the included studies, the addition of a posterior approach may further increase the invasiveness of the surgical procedure [6,7].

### Comparison with previous studies

Previous systematic reviews identified PW involvement as a risk factor for conversion to THA after acetabular fracture surgery (reported ORs, approximately 1.82 [23] and 1.81 [24]. In contrast, our analysis restricted to ABC fractures did not demonstrate a clear association between PW involvement and THA conversion. This apparent difference may reflect the narrower fracture population, selective fixation, small sample size, and variable follow-up; it should not be interpreted as evidence that PW involvement has no impact on long-term outcomes.

### Limitations

This study had several limitations that should be acknowledged. First, the number of included studies was small, limiting the statistical power of the meta-analysis and precluding further subgroup analyses. Because only two to four studies contributed to each pooled analysis, estimates of between-study heterogeneity and random-effects summary effects may also be imprecise and should be interpreted cautiously. In addition, high heterogeneity was observed in the analysis of operative time, limiting the precision of the pooled estimate. Accordingly, low $I^2$ values should not be considered evidence of true clinical or methodological homogeneity. Second, the indications for PW fixation varied substantially among the included studies, including differences in surgical approach, fixation strategy, and use of intraoperative stability assessment. Therefore, although this study summarized the available evidence, it could not determine a unified indication for PW fixation or provide definitive treatment guidelines. Third, all included studies were retrospective in design and were therefore subject to inherent methodological limitations. Long-term outcomes such as osteoarthritis and conversion to THA were not consistently reported according


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to PW fixation status, and follow-up duration varied across the included studies, with some patients having relatively short follow-up. Because these outcomes may develop over a prolonged period, their incidence may have been underestimated, limiting the ability to determine whether differences in reduction quality translate into clinically meaningful long-term outcomes. A sensitivity analysis restricted to patients with at least 24 months of follow-up was not feasible because patient-level follow-up and time-to-event data were unavailable. Fourth, the definitions of osteoarthritis and poor reduction varied across studies in terms of grading systems, imaging modalities, and dichotomization thresholds. Therefore, the pooled estimates may have combined outcomes that were not fully clinically equivalent and should be interpreted cautiously.

### Implications

Future studies should evaluate the clinical impact of PW involvement and fixation, while adjusting for fracture severity, reduction quality, and other relevant covariates.

### Conclusions

The presence of a PW fragment in ABC acetabular fractures showed no clear association with inferior reduction quality, osteoarthritis, or conversion to THA, although the osteoarthritis and THA findings should be interpreted cautiously because of variable follow-up. Among patients with ABC fractures and PW involvement, a clear difference in reduction quality was not demonstrated between PW fixation and nonfixation, although nonfixation showed numerically higher odds of poor reduction. In unadjusted comparisons of non-randomized cohorts, patients who underwent PW fixation had longer operative time and greater blood loss. These differences cannot be attributed to fixation itself because of confounding by indication and the frequent use of an additional posterior approach. Current evidence does not clearly support routine fixation of all PW fragments. Selective fixation based on residual displacement, joint congruency, and hip stability appears reasonable, although the certainty of the available evidence remains limited. Additional fixation should be considered selectively based on residual displacement, joint congruency, and hip stability after reconstruction of the main ABC components.

## Article Information

### Author contributions

Conceptualization: CHK. Data curation: CHK, EJL. Formal analysis: CHK, EJL. Methodology: CHK, EJL. Writing-original draft: EJL. Writing-review & editing: CHK. All authors read and approved the final manuscript.

### Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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### Data availability

The data analyzed in this systematic review and meta-analysis were derived from previously published studies. All relevant data are available in the original articles cited in this manuscript.

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### Supplementary materials

Supplementary materials related to this article can be found online at https://doi.org/10.12671/jmt.2026.00248.

**Supplementary Fig. 1.** Comparison according to presence of PW fragment.

**Supplementary Fig. 2.** Comparison according to fixation of PW fragment among ABC+PW.

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# Definitions and assessment of residual distal radioulnar joint instability after operative fixation of distal radius fractures: a methodological systematic review

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**Background:** Residual distal radioulnar joint (DRUJ) instability after operative fixation of distal radius fractures serves as an eligibility criterion, treatment indication, and outcome, but previous syntheses report inconsistent definitions. This methodological systematic review examined how clinical reports define, assess, and report it, and whether they distinguish it from structural triangular fibrocartilage complex (TFCC) lesions.

**Methods:** MEDLINE (PubMed) and Embase were searched from 2015 to 3 August 2026 for adult clinical reports in which residual DRUJ instability was assessed after fixation, or inferred from TFCC lesion characteristics, and used for a treatment decision or as an outcome. Every report entering full-text eligibility was assessed independently in duplicate; data were locked before agreement was calculated and disagreements disclosed. No risk-of-bias tool was applied: neither treatment effects nor diagnostic accuracy were estimated. Findings are counts and proportions; no meta-analysis was performed.

**Results:** Of 1,040 records, 697 were screened and 69 assessed as full texts; 30 reports of 27 cohorts were included, contributing 57 assessments. In the treatment-decision context, 12 reports stated an operational definition (40.0% of all 30; 50.0% of the 24 containing such an assessment), four stated neither required element (16.7% of 24), and six contained no such assessment and were classified as not applicable. At the assessment level, the positive criterion was vague in 43.9% and absent in 17.5%, and explicit for 48.0% of intraoperative but 25.9% of final follow-up assessments. No report inferred instability from a TFCC lesion instead of testing the joint; one used the two constructs interchangeably, 14 (46.7%) distinguished them, and 15 (50.0%) addressed instability without structural verification. A comparable prevalence estimate was extractable from only 9 of 57 assessments (15.8%).

**Conclusions:** Residual DRUJ instability is therefore assessed frequently but is often incompletely defined, and until these elements are stated consistently, frequency estimates cannot be compared across studies.

**Level of evidence:** Not applicable.

**Keywords:** Joint instability; Radius fractures; Triangular fibrocartilage; Distal radioulnar joint; Systematic review

**Systematic Review**

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## Introduction

Distal radioulnar joint (DRUJ) instability appears throughout the clinical literature on distal radius fracture in four different roles at once: as an eligibility criterion, as a diagnostic construct, as an indication for adjunctive stabilization such as triangular fibrocartilage complex (TFCC) repair or ulnar styloid fixation, and as an outcome measure. A construct asked to do this much work requires a clear operational definition and transparent reporting of how it was assessed.

Two independent syntheses suggest that it is not. A systematic review and meta-analysis of the management of acute DRUJ instability after distal radius fracture found that the method and frequency of screening for instability varied markedly across studies, because no reference standard for its diagnosis exists in this setting; the absence of a diagnostic reference standard, alongside the absence of a standardized treatment algorithm, was identified as the motivating problem of that review [1]. A systematic review and meta-analysis of operative versus nonoperative treatment of ulnar styloid base fractures reported that the included studies gave limited or no detail on clinical DRUJ instability after radius fixation, so that planned subgroup analyses could not be undertaken, and stated in its limitations that its findings could not be used to distinguish subgroups defined by DRUJ instability [2]. Both reviews encountered the same obstacle from opposite directions, and both recorded it as an impediment rather than examining it.

An interdisciplinary Delphi consensus published in 2023 addressed the imaging assessment of DRUJ instability and TFCC injury and proposed a division of roles between modalities [3]. That work is a recommendation for practice; it did not audit what clinical studies have reported.

Two further considerations motivate the present review. First, structural TFCC lesion and functional DRUJ instability are conceptually distinct states that do not invariably coincide, and the extent to which clinical reports distinguish them has not been examined systematically. Second, ulnar styloid fracture morphology is frequently invoked in this population as evidence bearing on DRUJ stability, introducing a third construct into the same chain of reasoning.

No systematic review has evaluated how clinical reports of operatively fixed distal radius fractures define, assess and report residual DRUJ instability, nor how they relate that construct to structural TFCC lesion. The objective of this review is to determine the proportion of such reports that provide an explicit operational definition of residual DRUJ instability in the postfixation treatment-decision context—one specifying both the assessment method and the criterion distinguishing a stable from an unstable joint—and, as a coprimary objective, to classify how each report relates structural TFCC lesion to functional DRUJ instability.

## Methods

### Protocol and registration

The protocol was registered on the Open Science Framework (registration DOI 10.17605/OSF.IO/U7AST) before the formal screening and eligibility decisions used in this review; that registration is frozen and publicly accessible and is the registration of record for the date on which the protocol was fixed. Preliminary screening and preliminary full-text reading undertaken during protocol development, before registration, were not carried forward and were repeated after registration. A PROSPERO record (CRD420261460209) was published subsequently and has been updated to reflect the completed screening and extraction stages. Amendment 1 (30 July 2026) recorded three corrections made at registration: preregistration full-text eligibility decisions were not carried forward and every report entering the full-text stage was reassessed; the construct boundary was stated as eight operational rules; and judgments resting on static alignment indices were recorded for every report assessed at full text irrespective of eligibility. A dated postregistration amendment log is deposited with the review. Reporting follows Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 [4] and, for the search, PRISMA-S [5].

### Ethics statement

It is a literature-based study; therefore, neither approval by the institutional review board nor the obtainment of informed consent is required.

### Eligibility criteria

Adult clinical reports published from 1 January 2015 onwards were eligible where (1) a distal radius fracture underwent operative fixation; (2) residual DRUJ instability was directly assessed, or explicitly inferred from TFCC le-


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sion characteristics, after fixation; and (3) that assessment or inference was used for postfixation study inclusion or stratification, adjunctive TFCC repair, DRUJ pinning, ulnar styloid fixation, immobilization strategy, or outcome assessment. The disjunction in criterion (2) is deliberate: restricting eligibility to direct stability testing would have excluded, at the eligibility stage, precisely the reports that the coprimary outcome is designed to characterize.

The registered protocol specified the exclusion criteria as a closed list, applied at full text in the order given and recorded as a single principal reason per report. A report was excluded where the population was treated nonoperatively, or where an operatively treated subgroup could not be separated from a mixed population; where neither a postfixation assessment of DRUJ stability nor an explicit inference from TFCC lesion characteristics was made, a report presenting only static alignment indices being assigned to this category; where every assessment preceded fixation; where the population was an isolated TFCC-injury cohort or otherwise outside the population of interest; or where the report was nonclinical, or was a review, a case report or a technical note. Continuing in the same order, a report was excluded where only an abstract was available; where the report was a duplicate or subsidiary publication of an eligible report and was not independently eligible; where an assessment was made but its time point could not be established; where the population was not adult; or where a postfixation assessment was established but was not used for any of the permitted purposes. Single-arm case series in which fewer than 10 analyzed participants had undergone operative fixation of a distal radius fracture were also excluded; the threshold applies to the number of analyzed participants with an operatively fixed distal radius fracture and not to the total enrolled sample. Failure to obtain a full text, and inability to read a full text that had been obtained, were recorded as retrieval and assessability statuses rather than as exclusion reasons, and are reported separately.

A prespecified construct boundary distinguished the object of the review from adjacent constructs. Structural TFCC lesion, fracture or implant stability, other carpal instabilities, and static radiographic, computed tomography or magnetic resonance alignment indices (ulnar variance, palmar tilt, radial height and inclination, coronal shift, sigmoid notch gap or step, congruency, radioulnar ratio, radioulnar line, epicenter, subluxation ratio, Mino-type classification) do not by themselves satisfy criterion (2); a report presenting only such measures was not eligible. Reports derived from the same or overlapping cohort were not automatically excluded: they were retained, linked to one another as a pair, and analyzed at report level, with a principal report designated per cohort for a prespecified sensitivity analysis. The cohort identifiers recorded during extraction are report-specific; the linkage between overlapping reports is stated separately and is reported in Supplementary Table 1.

### Information sources

MEDLINE (via PubMed) and Embase were searched from 1 January 2015 to the search date; searches were run on 28 July 2026 and updated on 3 August 2026. No language or species filters were applied. Backward and forward citation searching of included reports and of relevant existing systematic reviews supplemented the database searches. Grey literature and trial registries were not searched. The search of record is that of 3 August 2026, which falls within 30 days of submission as the protocol requires.

### Search strategy

The full strategies for both databases, with the proximity operators used to bind *stability* and *instability* to radioulnar terminology, the number of records returned at each line, and a structured self-assessment against the PRESS 2015 checklist [6], are given in Supplementary Material 1.

### Selection process

Every record was screened at title and abstract by reviewer 1. Records excluded at that stage for apparent absence of a postfixation assessment were reexamined at full text, because such assessment is frequently reported only outside the abstract; the number of decisions changed on reexamination is reported. Every report entering the full-text stage was assessed independently and in duplicate by two reviewers, with no sampling. Each reviewer recorded a decision, a principal exclusion reason from a prespecified list, and supporting verbatim quotations with their location. The two sets of decisions were locked before agreement was calculated and before any disagreement was disclosed. Disagreements were resolved by discussion, and by a third reviewer where discussion did not resolve them.

A large language model was used for title and abstract prescreening during protocol development; every record

it marked was subsequently read and judged by reviewer 1, who was masked to the label it had produced, and every title and abstract decision used in this review is a decision of reviewer 1. The full disclosure appears under "Disclosure of generative AI use."

Where the written rules proved ambiguous during assessment, a rule query was raised without identifying the report in question; the resulting interpretation was issued to both reviewers in identical wording, and any report whose decision could have changed was reassessed. Four such queries were issued, all after registration. The first established that reexamination at full text of records excluded at title and abstract is a recheck of screening rather than entry to the full-text stage, and required no reassessment because no decision was reversed; the second and third concerned the scope of the term *assessment* in the exclusion codes and the application of the duplicate-report code, and prompted each reviewer to reassess 12 reports; the fourth operationalized the prospective-versus-retrospective stratification and is described under *Synthesis methods*.

### Data collection process

Extraction took place after registration using a structured workbook at two levels: one row per report, and one row per assessment, where an assessment is one method combination × one time point × one criterion rule × one denominator. Values recorded during protocol development were discarded.

One reviewer extracted all items from all included reports. A second reviewer independently coded the definition level, the lesion-instability relationship, the follow-up definition level and the assessment-level core fields in all included reports, and independently extracted the remaining items in a validation subset of eight reports—the greater of five reports or 25% of the included set—selected by simple random sampling in R from the 31 reports included at the time the extraction data were locked (set.seed(20260724), reports sorted by ascending identifier; R 4.3.3). One of those eight was subsequently excluded when a prespecified eligibility criterion was reassessed, and the subset was not redrawn. All other fields were extracted once and verified against the full text by the second reviewer; this verification procedure is not independent duplicate extraction and is not described as such. Disagreements at every extraction stage were resolved by discussion after agreement had been calculated and locked.

### Data items

Data items comprised study characteristics; the operational definition of residual DRUJ instability in the treatment-decision context and its level; assessment method, composite-test status, criterion logic, verbatim positive criterion and its level, time point as reported and standardized, temporal phase, contralateral comparison, forearm position, anesthetic state, purpose of assessment, denominator and frequency; TFCC verification method and extent; use of ulnar styloid status; the threshold linking instability to treatment; and the follow-up definition.

The primary outcome is the proportion of included reports providing an explicit operational definition of residual DRUJ instability in the postfixation treatment-decision context. The coprimary outcome is the classification of the relationship each report draws between structural TFCC lesion and functional DRUJ instability. Assumptions about missing or unclear information were resolved by the prespecified coding rules; where a field could not be established from the full text it was coded *unclear* or *not reported* and is reported as such rather than imputed.

### Study risk-of-bias assessment

Conventional risk-of-bias tools were not applied, because the review estimates neither treatment effects nor test accuracy. Threats relevant to a reporting audit—overlapping reports, unclear applicability, incomplete methodological description, and whether definitions were prespecified in the *Methods* or inferred from the *Results*—were documented through structured extraction and addressed in sensitivity analyses. Levels of evidence were not assigned to individual reports.

### Effect measures

No effect measure was used. The review reports proportions of reports and of assessments meeting prespecified reporting conditions; it does not estimate an association or a treatment effect, so risk ratios, odds ratios and mean differences do not arise.

### Synthesis methods

Because the review describes the complete set of eligible


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reports identified within the prespecified search frame and makes no inferential claim to a superpopulation of reports, results are presented as counts and proportions, number (%), without confidence intervals. Confidence intervals are reported only for the reviewer-agreement statistics, where the quantity estimated is the reproducibility of a rating process rather than a fixed attribute of a fixed set of reports.

Composite reporting scores and multivariable modeling were not used; a composite score would require an arbitrary assumption of equal item weight. Three stratifications were prespecified: publication-year band (2015–2020 versus 2021 onwards), whether TFCC lesion was verified, and prospective-versus-retrospective design. Because the study-design item does not by itself indicate the direction of recruitment and data collection for case series and comparative studies, an operational rule was agreed and issued as a rule query: randomized trials and prospective cohorts were classified as prospective and retrospective cohorts as retrospective; case series and comparative studies were classified individually according to the direction stated in the full text; a prospectively maintained database reviewed retrospectively for the present study was classified as retrospective; and reports whose direction could not be determined were excluded from that stratification, with the number excluded reported. Two sensitivity analyses accompanied the primary analysis: one restricted to a single principal report per cohort, and one restricted to reports in which all analyzed participants had an operatively fixed distal radius fracture. As a supplementary descriptive analysis, the distribution of definition levels is also reported among reports containing at least one assessment made in the treatment-decision context. Reports without an assessment in a treatment-decision context were retained as not applicable, rather than combined with the none category, in all analyses of the operational-definition outcome, including the stratified and sensitivity analyses.

Agreement between reviewers was calculated after both reviewers' data were locked and before any disagreement was disclosed; agreement calculated after resolution is not reported. Eligibility decisions were analyzed as three categories using simple agreement and unweighted Cohen's κ with 95% confidence intervals. Exclusion codes were analyzed among reports both reviewers excluded. Assessment-level records were matched on an anchor composed only of nonjudgmental information—report identifier and time point as reported and standardized—with denominator and the verbatim names of the group and of the test used to break ties; judged fields were compared after matching and were not used to match, and unmatched records were excluded from field-level denominators. The definition level and the follow-up definition level are ordinal and were analyzed with linear-weighted κ; the lesion-instability relationship is nominal and used unweighted κ; contralateral use was analyzed principally as a binary contrast. Agreement proportions and disagreement patterns are the principal reliability measures and κ is supplementary; for the validation subset (n=8) κ is reported as a point estimate without confidence intervals, because the asymptotic interval is unstable at that sample size.

### Reporting-bias assessment

Publication bias and selective outcome reporting were not assessed; funnel-plot and regression-based methods do not apply in the absence of a synthesized effect estimate, and the review compares no publication with its protocol or its source data. Reporting completeness within published reports is the object of this review rather than a bias to be adjusted for, and is summarized as the proportion of reports or assessments in which each prespecified element was reported, was unclear, or was not reported.

### Certainty assessment

Grading of Recommendations Assessment, Development and Evaluation (GRADE) was not applied, because no effect estimate is produced for which certainty could be rated. Completeness of the evidence base is characterized instead by the number of included reports, the number of distinct cohorts, and the proportion of items coded *unclear* or *not reported*.

For the same reason no level of evidence is assigned. The Centre for Evidence-Based Medicine levels grade the design of a study against the question it answers—of treatment benefit or harm, diagnostic accuracy, prognosis or prevalence. This review answers none of those questions: it characterizes how a construct is defined, assessed and reported in published work, and its unit of analysis is a report, not a patient. A level assigned here would grade the included reports rather than this review, and would imply that an effect was estimated. The abstract therefore records the level as *not applicable*.

## Results

### Study selection

The database searches of 3 August 2026 identified 1,040 records: 466 from MEDLINE via PubMed and 574 from Embase. After 343 duplicates were removed, 697 unique records were screened at title and abstract and 628 were excluded. All 69 reports entering the formal full-text eligibility stage were retrieved and were assessed independently in duplicate. Thirty-nine were excluded and 30 reports were included, deriving from 27 distinct cohorts—three pairs of reports draw on overlapping cohorts and were retained, linked as pairs and analyzed at report level. The three pairs are identified in Supplementary Table 1. The flow of records is shown in Fig. 1.

One report that was included when the extraction data were locked was subsequently excluded, after both reviewers independently reassessed it against the prespecified minimum-sample criterion for single-arm case series and both concluded that the report failed the prespecified minimum-sample requirement: fewer than 10 of its analyzed participants had had an operatively fixed distal radius fracture. The final included set therefore comprises 30 reports, and the exclusion is counted in Fig. 1 among the reports excluded at full text with reasons. Agreement statistics computed on the locked data were not recalculated, for the reason given under *Agreement between reviewers*.

Separately from that stage, a supplementary audit of title and abstract exclusions was carried out, because a postfixation assessment is frequently reported only outside the abstract. A total of 127 records were selected for the audit. They are every record carrying either of the two exclusion reasons that turn on the apparent absence of a postfixation assessment, and not a sample of them: 148 records carried one of those reasons, 21 of which had already entered the full-text stage on other grounds and were therefore already read, leaving 127. Full texts were obtained for 118 and reexamined, no decision was reversed, and full texts could not be obtained for the remaining nine. The full-text eligibility set was therefore unchanged. Under the interpretation issued during conduct, this audit is a recheck of title and abstract screening and not entry to the full-text stage, so those nine are not counted in the flow diagram as reports sought but not retrieved; they are shown separately in Fig. 1. Citation searching identified one additional report, published in a Chinese-language journal; it was sought, could not be retrieved, and is shown separately in the *identification via other methods* arm of Fig. 1, from which no report entered the eligibility stage. It is not one of the nine above and entered neither the audit nor the database arm of the flow.

Agreement between the two reviewers on the initial independent full-text decisions, calculated on locked data before any disagreement was disclosed, was 94.2% across the three decision categories (unweighted $\kappa$, 0.88; 95% confidence interval [CI], 0.77–0.99), and 78.4% for the principal exclusion code among reports both reviewers excluded ($\kappa$, 0.71; 95% CI, 0.54–0.88). All disagreements were resolved by discussion; no report required third-reviewer adjudication. Following two of the four rule-query interpretations each reviewer reassessed 12 reports, after which eligibility changed for one report for reviewer 1 and three for reviewer 2. As the protocol requires, agreement was not recalculated after resolution, so the figures above describe the reviewers' initial independent judgments and not the outcome of discussion.

### Study characteristics

The 30 included reports [7-36] were published between 2015 and 2026. Their characteristics are given in Table 1; report-level characteristics and the item-level coding for each report individually are given in Supplementary Table 1, in which the reports appear in the order of references [7-36].

Applying the operational rule for the direction of recruitment and data collection, 10 reports were classified as prospective and 17 as retrospective; the direction of three [15,33,36] could not be determined from the full text, and these were excluded from that stratification. All 30 reports satisfied the condition that every analyzed participant had an operatively fixed distal radius fracture. A total of 57 assessments were recorded—one assessment being one combination of method, time point, criterion rule and denominator.

Three pairs of reports draw on overlapping cohorts, giving 27 distinct cohorts; the pairs are identified in Supplementary Table 1 and are the subject of the first sensitivity analysis.

### Risk of bias in studies

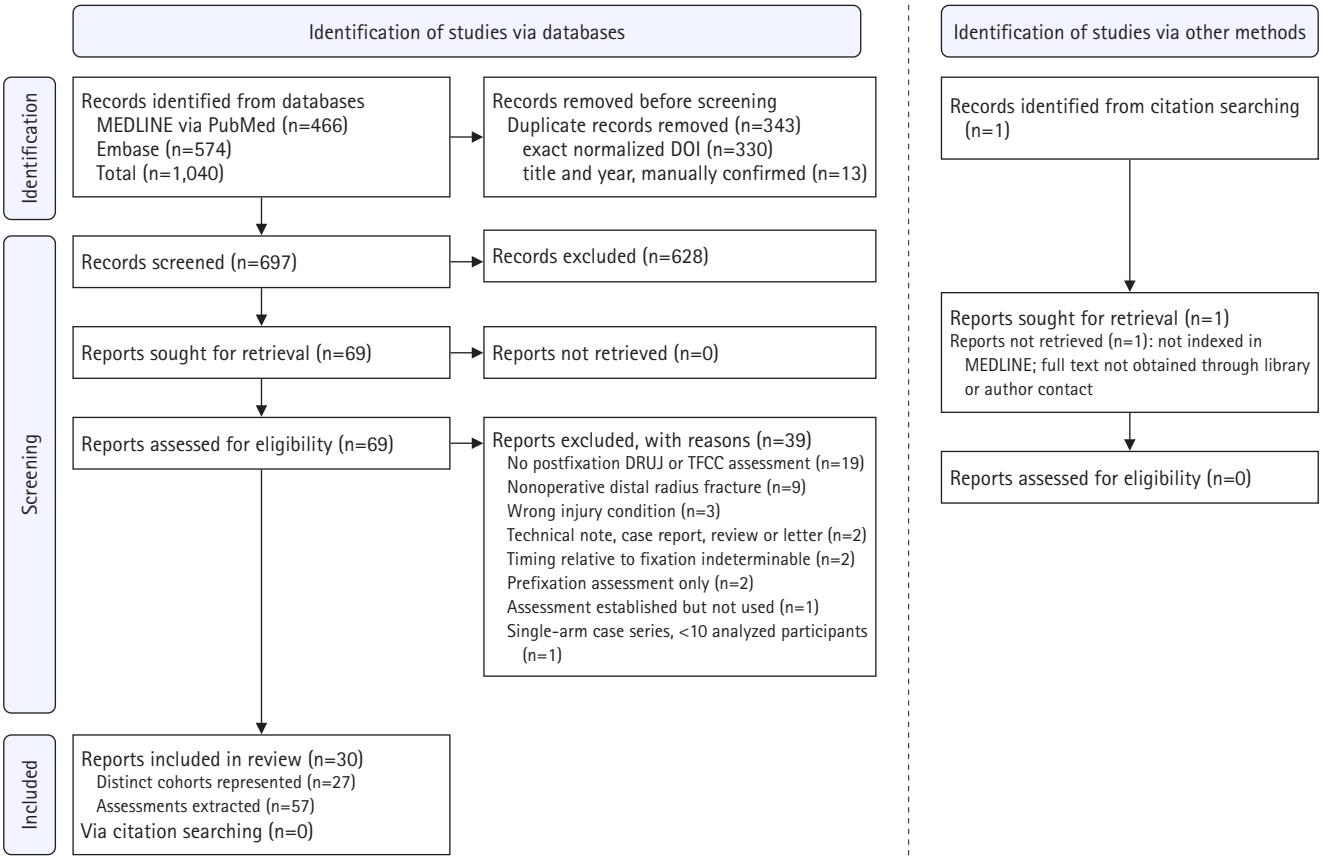
No conventional risk-of-bias assessment was undertaken, for the reason given in the Methods. The report-level threats that were documented are reported with the find-


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ings they bear on: overlapping cohorts are addressed in the first sensitivity analysis; applicability is addressed by the second; and whether the definition was stated in the Methods or recovered from the Results is reported as a separate item in Table 2.

### Results of individual studies

The item-level coding for every one of the 30 included reports is given in Supplementary Table 1. The verbatim positive criterion for every one of the 57 assessments, alongside the level assigned to it, is given in Supplementary Table 2. A




Searches were run on 3 August 2026. All 69 reports entering the full-text stage were assessed independently and in duplicate; no sampling was applied. Both reviewers' decisions were locked before agreement was calculated and before any disagreement was disclosed, and agreement was not recalculated after resolution.

Reports drawn from overlapping cohorts were retained rather than excluded and are identified as linked pairs in Supplementary Table 1; a sensitivity analysis restricted to one principal report per cohort is reported. Exclusion reasons are the principal reason recorded for each report; subsidiary reasons are given in the deposited dataset.

One report initially included was excluded on 6 August 2026 after re-adjudication against eligibility criterion 9 (single-arm case series with fewer than 10 analyzed participants); the judgment was made by the two reviewers and is recorded in the amendment log. The development search of 28 July 2026 (1,036 identified, 341 duplicates, 695 screened) is superseded by the figures above.

**Fig. 1.** Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 flow diagram for identification, screening, and inclusion of reports. Records identified through database searches and citation searching are shown separately. The audit of title and abstract exclusions shown below the flow diagram is not part of the PRISMA flow: records excluded at title and abstract for apparent absence of a postfixation assessment were reexamined at full text, and no decision was reversed. DRUJ, distal radioulnar joint; TFCC, triangular fibrocartilage complex.

**Table 1.** Characteristics of the 30 included reports

| Characteristic | No. (%) |
|---|---|
| Year of publication | |
| 2015–2020 | 11 (36.7) |
| 2021–2026 | 19 (63.3) |
| Study design | |
| Case series | 10 (33.3) |
| Retrospective cohort | 10 (33.3) |
| Prospective cohort | 5 (16.7) |
| Randomized trial | 4 (13.3) |
| Comparative study | 1 (3.3) |
| Direction of recruitment and data collection | |
| Retrospective | 17 (56.7) |
| Prospective | 10 (33.3) |
| Could not be determined | 3 (10.0) |
| Language of publication | |
| English | 26 (86.7) |
| Czech | 3 (10.0) |
| Chinese | 1 (3.3) |
| Assessments contributed per report | |
| One | 11 (36.7) |
| Two | 12 (40.0) |
| Three | 6 (20.0) |
| Four | 1 (3.3) |
| All analyzed participants had an operatively fixed distal radius fracture | 30 (100) |
| Contained at least one assessment made in a treatment-decision context | 24 (80.0) |

complete inventory of the judgments resting on static alignment indices is given in Supplementary Table 3. All three tables carry the reference number for included reports, so any row corresponding to an included report can be matched to the citation.

## Results of syntheses

### Primary outcome—operational definition of residual DRUJ instability

The distribution of definition levels in the treatment-decision context is given in Table 2. Of the 30 reports, 12 (40.0%) state an operational definition of residual DRUJ instability explicitly, eight (26.7%) state one of the two elements, four (13.3%) state neither, and six (20.0%) contain no assessment made in a treatment-decision context at all, so that the question does not arise for them.

Those six are reported as not applicable rather than as an absent definition: a report cannot fail to define a construct

**Table 2.** Reporting of residual DRUJ instability at report level (n=30)

| Characteristic | No. (%) |
|---|---|
| Operational definition in the treatment-decision context (Item 5)—all 30 reports | |
| Explicit (both the assessment method and the criterion distinguishing stable from unstable were stated) | 12 (40.0) |
| Partial (one of the two was stated) | 8 (26.7) |
| None (neither was stated) | 4 (13.3) |
| Not applicable (the report contains no assessment made in a treatment-decision context) | 6 (20.0) |
| The same item among the 24 reports that contained such an assessment | |
| Explicit | 12 (50.0) |
| Partial | 8 (33.3) |
| None | 4 (16.7) |
| Location of the information on which the definition level was assigned (Item 6) | |
| Methods | 24 (80.0) |
| Results only | 4 (13.3) |
| Could not be located unambiguously | 2 (6.7) |
| Relationship between structural TFCC lesion and functional instability (Item 11) | |
| R1: distinct constructs | 14 (46.7) |
| R2: TFCC lesion used as a surrogate for instability | 0 |
| R3: conflated | 1 (3.3) |
| R4: instability addressed without structural verification | 15 (50.0) |
| R5: unclear | 0 |
| TFCC verification method (Item 9a) | |
| Not verified | 15 (50.0) |
| Arthroscopy | 7 (23.3) |
| Open inspection | 3 (10.0) |
| More than one method | 3 (10.0) |
| Magnetic resonance imaging | 2 (6.7) |
| Extent of verification (Item 9b) | |
| All participants | 9 (30.0) |
| Selected subgroup | 5 (16.7) |
| None | 15 (50.0) |
| Unclear | 1 (3.3) |
| Use of ulnar styloid status (Item 10) | |
| Not used | 15 (50.0) |
| Indication for adjunctive treatment only | 15 (50.0) |
| Both evidence of instability and indication for treatment | 0 |
| Evidence of instability only | 0 |
| Threshold linking instability to treatment (Item 16) | |
| Linked to a judgment, but no threshold stated | 9 (30.0) |
| Nonoperational or vague threshold | 7 (23.3) |
| Explicit threshold linked to treatment | 6 (20.0) |
| No link to treatment | 5 (16.7) |
| Not applicable | 3 (10.0) |
| Definition of persistent or recurrent instability at follow-up (Item 17) | |
| Explicit | 7 (23.3) |
| Partial | 12 (40.0) |
| None | 11 (36.7) |

DRUJ, distal radioulnar joint; TFCC, triangular fibrocartilage complex.


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in a context it never enters. They were eligible through the outcome-assessment limb of criterion (3) rather than the treatment-decision limb. Restricted to the 24 reports that do contain such an assessment—the supplementary denominator specified in the protocol, and the one to which the question directly applies—the distribution is explicit 12 (50.0%), partial 8 (33.3%), none 4 (16.7%). Those four used an assessment to inform a treatment decision without stating what was examined or what counted as positive. The registered primary analysis is the one over all 30 reports and is reported first throughout; the restricted denominator is given alongside it and is not substituted for it.

The information on which the definition level was assigned was located in the Methods in 24 reports (80.0%), in the Results only in four (13.3%), and could not be located unambiguously in two (6.7%). This item was coded for all 30 reports, including those in which no definition was found, and indicates where the relevant statement—or its absence—was established.

### Coprimary outcome—relationship between TFCC lesion and instability

Only three of the five prespecified categories were used (Table 2). No report described inferring instability from a TFCC lesion in place of testing the joint. One report used the two constructs interchangeably while also testing the joint, 14 (46.7%) distinguished them, and 15 (50.0%) addressed instability without structural verification.

Consistently, TFCC lesion was not verified in 15 reports (50.0%). Where verification was performed it was by arthroscopy in seven, open inspection in three, magnetic resonance imaging in two, and by more than one method in three.

### Secondary outcomes at report level

No report explicitly reported using ulnar styloid status as evidence of instability. Fifteen reports (50.0%) reported using it as an indication for adjunctive treatment and the remaining 15 (50.0%) did not report using it at all: in half of the included reports the ulnar styloid entered the treatment pathway as reported, and in none was it reported as entering the reasoning about stability. An explicit threshold linking instability to treatment was stated in six reports (20.0%). Cross-tabulating the definition at follow-up against the primary outcome, five reports (16.7%) define instability both at initial assessment and at follow-up; three (10.0%) define it at neither; and five (16.7%) define it initially but not at follow-up.

### How instability was assessed

Assessment-level characteristics are given in Table 3, overall and by temporal phase. Twenty-five of the 57 assessments were made intraoperatively and 32 postoperatively; five reports assessed intraoperatively only, seven postoperatively only and 18 (60.0%) at both. Twenty-seven of the 32 postoperative assessments were made at the final follow-up time point. Assessment-level proportions count reporting opportunities rather than studies or participants: a report contributing four assessments contributes four times to them, and the report-level counterpart of each principal finding is given alongside it below.

Reporting was less complete for postoperative, and particularly final follow-up, assessments than for intraoperative ones. An explicit positive criterion was recorded for 12 of the 25 intraoperative assessments (48.0%) but for seven of the 27 made at final follow-up (25.9%), while a vague criterion rose from nine (36.0%) to 14 (51.9%). The forearm position was recorded for 13 intraoperative assessments (52.0%) and five at final follow-up (18.5%), a contralateral comparison for 11 (44.0%) and seven (25.9%), and a prevalence estimate comparable across reports could be extracted from six (24.0%) and two (7.4%).

These are comparisons between groups of assessments, not paired observations, and the groups differ in composition as well as in timing. Restricted to the 18 reports that assessed at both times, where the comparison is within a report, the direction is the same but weaker. The highest criterion level recorded was lower postoperatively in six reports, unchanged in nine and higher in three. The forearm position was recorded intraoperatively but not postoperatively in six reports and in none the other way round. A contralateral comparison showed no within-report difference—three reports recorded one only intraoperatively, two only postoperatively, and 13 either both or neither. The between-group difference therefore reflects the composition of the assessments as well as any attenuation within a report, and is reported as such.

The criterion for a positive test is the weakest link. Fourteen reports (46.7%) contain at least one assessment with an explicit positive criterion. In three reports [9,21,36] no assessment had any stated criterion. In five reports (16.7%)—

**Table 3.** Characteristics of the 57 assessments, overall and by temporal phase

| Characteristic | All (n=57) | Intraoperative (n=25) | Postoperative (n=32) | Final follow-up (n=27) |
|---|---|---|---|---|
| Assessment method (more than one code may apply) | | | | |
| Ballottement or shuck test | 25 (43.9) | 9 (36.0) | 16 (50.0) | 12 (44.4) |
| Radioulnar stress, drawer or shift test | 13 (22.8) | 8 (32.0) | 5 (15.6) | 4 (14.8) |
| Not specified or not reported | 11 (19.3) | 5 (20.0) | 6 (18.8) | 6 (22.2) |
| Other, specified | 7 (12.3) | 0 | 7 (21.9) | 6 (22.2) |
| Piano-key test | 5 (8.8) | 0 | 5 (15.6) | 5 (18.5) |
| Unnamed intraoperative manual assessment | 2 (3.5) | 2 (8.0) | 0 | 0 |
| Stress radiography | 1 (1.8) | 1 (4.0) | 0 | 0 |
| Not performed | 1 (1.8) | 1 (4.0) | 0 | 0 |
| Level of the positive criterion | | | | |
| Explicit | 22 (38.6) | 12 (48.0) | 10 (31.3) | 7 (25.9) |
| Vague | 25 (43.9) | 9 (36.0) | 16 (50.0) | 14 (51.9) |
| None stated | 10 (17.5) | 4 (16.0) | 6 (18.8) | 6 (22.2) |
| Testing conditions | | | | |
| Contralateral comparison used | 23 (40.4) | 11 (44.0) | 12 (37.5) | 7 (25.9) |
| Contralateral comparison not reported | 34 (59.6) | 14 (56.0) | 20 (62.5) | 20 (74.1) |
| Contralateral comparison explicitly stated not to have been used | 0 | 0 | 0 | 0 |
| Forearm position reported | 21 (36.8) | 13 (52.0) | 8 (25.0) | 5 (18.5) |
| Anesthetic state reported | 55 (96.5) | 25 (100) | 30 (93.8) | 25 (92.6) |
| Composite judgment (more than one test combined) | 5 (8.8) | 0 | 5 (15.6) | 4 (14.8) |
| Frequency | | | | |
| Descriptive frequency extractable | 44 (77.2) | 15 (60.0) | 29 (90.6) | 24 (88.9) |
| Prevalence estimate comparable across reports | 9 (15.8) | 6 (24.0) | 3 (9.4) | 2 (7.4) |

Values are presented as number (%) of the assessments in that column. The final follow-up column is a subset of the postoperative column, not a fourth group, so the columns are not mutually exclusive and do not sum to 57. Percentages are of the column denominator.

the three above together with two others [13,33]—the assessment method itself could not be identified from the full text for any assessment.

Testing conditions were incompletely reported. A contralateral comparison was used in 23 assessments (40.4%), corresponding to 13 reports (43.3%). No report stated that a contralateral comparison was not used; the remaining 34 assessments are silent on the point.

A descriptive frequency could be extracted for 44 of the 57 assessments (77.2%). A prevalence estimate comparable across reports could be extracted for only nine (15.8%), corresponding to nine reports (30.0%). Comparability required all six prespecified conditions: the denominator is a cohort defined in advance; the sample was not selected by the result of the test; the numerator counts patients determined to have DRUJ instability; the same opportunity for assessment applied to the whole denominator or to a stated analysis set; the time point and threshold can be established; and the count is not a proxy such as the number of TFCC repairs or ulnar styloid fixations performed.

### Judgments resting on static alignment indices

Across all 69 reports assessed at full text, 11 (15.9%) advanced a judgment about instability resting on a static alignment index; three of these are in the included set [21,22,32]. The indices used were the Mino criteria, the radioulnar ratio, joint congruency and the sigmoid notch step. One further report advancing such a judgment was excluded at full text as a single-arm case series with fewer than ten analyzed participants (Fig. 1); it remains in the inventory, which covers every report assessed at full text irrespective of eligibility, as the protocol requires.

### Prespecified stratifications

Stratified distributions are presented descriptively in Table 4. The protocol specifies that interpretation be based on


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**Table 4.** The three prespecified stratifications of the primary and coprimary outcomes

| Stratum | No. | Definition explicit | Definition partial | Definition none | Definition not applicable | R1 distinct | R4 instability only | R3 conflated |
|---|---|---|---|---|---|---|---|---|
| 2015–2020 | 11 | 3 (27.3) | 3 (27.3) | 2 (18.2) | 3 (27.3) | 5 (45.5) | 6 (54.5) | 0 |
| 2021–2026 | 19 | 9 (47.4) | 5 (26.3) | 2 (10.5) | 3 (15.8) | 9 (47.4) | 9 (47.4) | 1 (5.3) |
| TFCC verified | 15 | 7 (46.7) | 5 (33.3) | 1 (6.7) | 2 (13.3) | 14 (93.3) | 0 | 1 (6.7) |
| TFCC not verified | 15 | 5 (33.3) | 3 (20.0) | 3 (20.0) | 4 (26.7) | 0 | 15 (100) | 0 |
| Prospective | 10 | 5 (50.0) | 1 (10.0) | 1 (10.0) | 3 (30.0) | 4 (40.0) | 5 (50.0) | 1 (10.0) |
| Retrospective | 17 | 7 (41.2) | 5 (29.4) | 2 (11.8) | 3 (17.6) | 9 (52.9) | 8 (47.1) | 0 |

Values are presented as number (%). The TFCC verification rows are definitional by construction and are not interpreted as an empirical association. A report that did not verify the structural lesion did not measure one of the two variables and was therefore classified as *instability addressed without structural verification* by the coding rule itself, which is why that column reads 15 (100). The rows are reported because the stratification was prespecified. Item 5 is reported in the same four categories as in Table 2: reports containing no assessment made in a treatment-decision context are shown as not applicable and are not counted as an absent definition, so the four definition columns sum to the stratum denominator. Three reports whose direction of recruitment could not be determined were excluded from the prospective-retrospective stratification, so that stratum totals 27 rather than 30. TFCC, triangular fibrocartilage complex.

the observed findings without prespecifying which category represents preferable practice, and no statistical comparison between strata was performed.

The stratification of the coprimary outcome by TFCC verification is definitional, not empirical. A report that did not verify the structural lesion could not empirically evaluate the relationship between structural TFCC lesion and functional instability, and was therefore classified, by the prespecified coding rule, as instability addressed without structural verification; among the 15 reports that did verify it, 14 treated the two constructs as distinct and one used them interchangeably. The rows are reported because the stratification was prespecified, and are labeled in the table as definitional so that they are not read as evidence of an association.

### Sensitivity analyses

One principal report per cohort (27 reports). Retaining [7], [28] and [34] as the principal report of each overlapping cohort, and setting aside [27], [12] and [35], the primary outcome was explicit 11 (40.7%), partial seven (25.9%), none four (14.8%), and not applicable five (18.5%), and the coprimary outcome distinct constructs 12 (44.4%), instability without structural verification 14 (51.9%), conflated one (3.7%). Both are materially unchanged from the primary analysis. The three reports set aside were coded explicit [12], partial [27] and not applicable [35], so the number of reports coded none is unchanged from the primary analysis and the number coded not applicable falls from six to five.

Reports in which all analyzed participants had an operatively fixed distal radius fracture. This condition held for all 30 reports, so the restricted analysis is identical to the primary analysis and is not reported separately.

## Agreement between reviewers

Agreement was calculated on locked data before any disagreement was disclosed and was not recalculated after resolution (Table 5). The extraction-stage figures were computed on the 31 reports that were in the included set when the data were locked; one of those reports was subsequently excluded on eligibility grounds (see *Study selection*), and the figures have not been recalculated on the remaining 30, in keeping with the registered rule that agreement is not recalculated once locked.

Assessment-level records were matched on nonjudgmental anchors, giving 51 matched pairs from 58 and 56 records respectively and an identification match proportion of 0.89. Requiring verbatim identity of the free-text anchor fields would have matched only two records, which is why the anchor was defined as identifying information rather than identical strings.

The two items on which the reviewers agreed least were whether a contralateral comparison was used and the extent of TFCC verification. This is considered in the *Discussion*.

For the validation subset $\kappa$ is given as a point estimate without a confidence interval, because the asymptotic interval is unstable at n=8 and its upper bound exceeds 1. The subset was drawn at random from the 31 reports then included; one of the eight was subsequently excluded on eligibility grounds, so seven of the eight are in the final

**Table 5.** Agreement between the two reviewers, calculated on locked data before disclosure (extraction stage: the 31 reports included at the time of locking)

| Stage and item | Agreement (%) | κ (95% CI where calculated) |
|---|---|---|
| Eligibility (69 reports) | | |
| Eligibility decision, three categories | 94.2 | 0.88 (0.77–0.99), unweighted |
| Principal exclusion code, among reports both reviewers excluded | 78.4 | 0.71 (0.54–0.88), unweighted |
| Extraction, all 31 reports included at locking | | |
| Definition level (Item 5) | 80.6 | 0.78 (0.62–0.95), linear-weighted |
| Lesion-instability relationship (Item 11) | 83.9 | 0.71 (0.49–0.92), unweighted |
| Follow-up definition level (Item 17) | 74.2 | 0.60 (0.36–0.83), linear-weighted |
| Extraction, assessment-level records (51 matched pairs from 58 and 56 records) | | |
| Contralateral comparison (Item 15) | 72.5 | 0.40 (0.15–0.65), binary contrast |
| Extraction, validation subset of 8 reports extracted independently | | |
| Location of the definition (Item 6) | 87.5 | 0.71 |
| TFCC verification method (Item 9a) | 75.0 | 0.67 |
| Extent of TFCC verification (Item 9b) | 62.5 | 0.49 |
| Use of ulnar styloid status (Item 10) | 100.0 | 1.00 |
| Threshold linking instability to treatment (Item 16) | 87.5 | 0.83 |

CI, confidence interval; TFCC, triangular fibrocartilage complex.

included set. The subset was not redrawn, because the second reviewer's independent extraction cannot be repeated on locked data.

### Reporting biases

No formal reporting-bias assessment was undertaken, for the reason given in the Methods. The within-report completeness findings are presented throughout the section above—the proportions of reports and assessments in which the method, the criterion, the testing conditions, the follow-up definition and the treatment threshold were not stated. They should not be read as evidence that an unreported procedure was not performed.

## Discussion

### Key results

Across 30 reports of 27 cohorts that assessed residual DRUJ instability after operative fixation of a distal radius fracture, an operational definition of the condition being assessed was frequently not stated: in the registered analysis of all 30 reports, 12 (40.0%) were classified as explicit, and among the 24 in which an assessment informed a treatment decision, 12 (50.0%). This deficiency is clinically relevant because posttraumatic DRUJ instability after distal radius fracture has been associated with worse wrist scores and greater pain, without correlation to conventional radiographic parameters [37], and with impaired self-reported hand function despite preserved forearm-rotation strength at longer follow-up [38]. In four reports an assessment informed a treatment decision although neither element was stated. The six that contain no such assessment are reported as not applicable rather than as failing to define, and both denominators are given throughout rather than one in place of the other.

The field is more consistent about *what test to perform* than about *what the test means*. Ballottement or shuck testing accounts for 43.9% of the 57 recorded assessments, and the named maneuvers together account for most of the remainder—but the criterion for a positive result was vague in 43.9% of assessments and absent in a further 17.5%. In three of the 30 reports no assessment had any stated criterion at all, and in five the assessment method itself could not be identified from the full text. The three reports without any stated criterion were among the five reports in which the assessment method could not be identified.

Definition reporting was less complete at follow-up than at the initial assessment. Only five reports of 30 define instability both at the initial assessment and at follow-up, while five define it initially but do not restate the definition when reporting persistence or recurrence. A reader of that second group can establish what the authors meant by in-


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stability at the time of surgery but not what they meant by it at follow-up—the point at which persistence or recurrence is claimed.

## Interpretation

### The two constructs were rarely conflated but seldom assessed together

We expected to find reports substituting a TFCC lesion for a functional assessment—inferring instability from a lesion without testing the joint. None reported doing so. Structural TFCC lesion and functional DRUJ instability were rarely conflated in the published reports but were often not assessed together: no report described inferring instability from a lesion in place of testing, one used the two interchangeably while also testing the joint, 14 (46.7%) distinguished them, and 15 (50.0%) addressed instability without any structural verification. The dominant problem is not conflation but absence of contact between the two.

This is also why the prespecified stratification by TFCC verification does not provide an empirical comparison of the lesion-instability relationship, and is reported with that label attached rather than interpreted. A report that does not verify the lesion has not measured one of the two variables and so cannot evaluate the relationship between them empirically; its classification follows from the coding rule rather than from an observed association, and the stratification is definitional rather than empirical. The finding is not the tautology but what produces it—that in half of this literature the structural lesion was never assessed. In consequence, the relationship between structural lesion and functional instability—a relationship the field routinely invokes when justifying adjunctive repair [1,3]—cannot be examined empirically at the level of the published record, because in those reports only one of the two variables exists. It would require primary studies that verify the lesion and test the joint in the same patients and report both.

An adjacent finding points the same way. No report explicitly reported using ulnar styloid status as evidence of instability, but 15 (50.0%) reported using it as an indication for adjunctive treatment. Ulnar styloid status was reported in this literature as a treatment trigger rather than as a diagnostic sign, and it was reported without passing through an explicit statement about stability. Whatever the merits of that practice, it is not visible as an inference and so cannot be evaluated as one.

### Silence is not a finding of absence

No report stated that a contralateral comparison was not performed. Twenty-three assessments (40.4%) recorded one and the remaining 34 are simply silent. A reader could reasonably conclude either that the comparison was not made or that it was made and not reported, and nothing in the reports distinguishes these. The same asymmetry runs through the extraction: reports state what they did and rarely state what they did not do, so every absent field carries two readings at once. Published reports can be incomplete representations of study conduct: protocol-to-publication comparisons have shown that methodological details and prespecified outcomes may be incompletely reported or omitted from the final publication [39,40].

This has a direct consequence for how the present figures should be read. Proportions such as 40.4% are the proportion of assessments in which a contralateral comparison was reported, not the proportion in which it was performed. We have written them that way throughout, and readers of this literature should do the same.

### Where agreement was lowest

Agreement between the two reviewers was higher for the definitional items—80.6% for definition level and 83.9% for the lesion-instability relationship—but fell to 72.5% (κ, 0.40) for whether a contralateral comparison was used, across the 51 matched assessment records, and to 62.5% (κ, 0.49) for the extent of TFCC verification in the eight-report subset extracted independently. These are the two lowest values recorded, and both concerned information that was frequently absent from, or difficult to establish in, the source reports. The lower agreement may partly reflect ambiguity in source reporting, a recognized contributor to divergent reviewer interpretations in methodological assessments [41]; the coding rules, the small subset denominator and uncertainty in assessment-level record matching may also have contributed; these figures were fixed before any disagreement was disclosed and, as the protocol requires, were not recalculated after resolution.

### Frequency cannot presently be compared across reports

A descriptive frequency of residual instability could be extracted from 77.2% of assessments, but a prevalence estimate comparable across reports—one meeting all six prespecified conditions, including a denominator defined in advance, a

sample not selected by the result of the test, and an establishable time point and threshold—could be extracted from only 15.8% (nine of 57 assessments), corresponding to nine of the 30 reports. Any pooled estimate of the frequency of residual DRUJ instability after operative fixation drawn from the current literature would therefore be assembled from denominators that do not mean the same thing. The decision not to meta-analyze, taken at registration, is supported after the fact by the data rather than by preference.

### Comparison with previous studies

The two earlier syntheses that approached this literature met the same obstacle and recorded it rather than quantifying it. One found that the method and frequency of screening for instability varied markedly across studies and attributed the variation to the absence of a diagnostic reference standard [1]; the other found the detail on clinical DRUJ instability after radius fixation so limited that planned subgroup analyses could not be undertaken [2]. Neither examined the reporting itself. The present review supplies the missing quantity: the proportion of reports in which the construct is defined at all, and the proportion of assessments in which the criterion that converts a maneuver into a diagnosis is stated.

The 2023 interdisciplinary Delphi consensus on imaging assessment of DRUJ instability and TFCC injury is complementary rather than overlapping [3]. It prescribes how the joint should be imaged; the present review describes what clinical reports have actually stated about how they assessed it, and the two together mark the distance between recommendation and practice.

### Strengths and limitations

The protocol was registered before the formal screening and eligibility decisions used in the review; preliminary screening and preliminary full-text reading carried out during protocol development were not carried forward and were repeated after registration, and every subsequent departure is recorded in a dated amendment log deposited with the review. Every report entering the full-text stage was assessed independently and in duplicate, with no sampling. Both reviewers' data were locked, with file hashes and timestamps, before agreement was calculated and before any disagreement was disclosed; agreement was not recalculated after resolution, so the figures reported describe initial independent judgment rather than the outcome of discussion. The calculation script refuses to run unless both lock confirmations are present, so no reported agreement figure can have been produced after disclosure. Questions of interpretation that arose during conduct were raised without identifying the report in question and answered by a third reviewer in wording issued identically to both. The verbatim criterion text for all 57 assessments and the item-level coding for all 30 reports are provided in the supplementary materials, so every judgment reported here can be checked against its source.

Screening at title and abstract was performed by one reviewer, not in duplicate. The supplementary audit of title and abstract exclusions reported above was carried out to mitigate this: of 127 records selected, 118 were reexamined at full text and no decision was reversed. Full texts could not be obtained for the remaining nine, whose titles and abstracts gave no indication of a postfixation assessment.

Not every item was extracted independently in duplicate. One reviewer extracted all items; a second independently coded the definitional items and the assessment-level core fields in all reports and independently extracted the remaining items in a random subset of eight. Other fields were extracted once and verified against the full text, which is not independent duplicate extraction and is not described as such. Agreement for the independently extracted subset is reported with its denominator of eight, and $\kappa$ is given as a point estimate only.

The search was not peer reviewed by an information specialist. A structured self-assessment against the PRESS 2015 checklist [6] was carried out after execution and is reported in full (Supplementary Material 1). It identified three weaknesses: the absence of a joint-instability subject heading in either database, differing proximity distances between the two, and the absence of the hyphenated form *radio-ulnar* from the PubMed proximity terms. The registered strategy was not amended, because amending it would have made the search of record a mixture of the registered and a revised form. The two weaknesses capable of costing an eligible report were instead tested directly: a diagnostic query combining the population block with the missing elements, and excluding everything the registered strategy already retrieves, returned 98 records, none of which met the eligibility criteria on title and abstract. The set was dominated by elbow injury, because the subject


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heading *Radius fractures* is not restricted to the distal radius, and by fracture and carpal instability—the adjacent constructs the review's construct boundary excludes. This test cannot exclude a report that assesses instability and never says so in its title or abstract; that class is bounded by the supplementary audit described above.

Four included reports are not published in English—three in Czech [33-35] and one in Chinese [30]. All four were read with machine-assisted translation, and confirmation by a fluent speaker was not sought for any of them. In the three Czech reports, the definition level was coded *partial*, *none* or not applicable; absent or incomplete reporting is harder to establish through translation than the presence of an explicit statement. The Chinese report carries a full English abstract, but every value coded from it rests on the Chinese body text rather than on that abstract. The material on which each coding rests is deposited verbatim in the source language, so any reader with the language can check it.

Chinese-language databases were not searched, and one report identified through citation searching could not be obtained. Grey literature and trial registries were not searched; the object of the review is the reporting practice of published reports, which makes the restriction defensible, but it is a restriction.

The assignment of a criterion to the *vague* category is a judgment. We have published the verbatim text of all 57 criteria alongside the level assigned to each so that readers may disagree with any of them individually.

Reports published before 2015 were not eligible, so the findings describe current rather than historical practice, and the earlier band contains 11 reports, which limits what the year stratification can show. With denominators of this size, small differences between categories and between strata should not be read as stable features of the literature.

## Implications

The elements in Table 6 are derived from what these 30 reports reported and left unreported, not from expert opinion, and each is tied to the corresponding finding in the present sample. They are offered as a starting point for subsequent Delphi work or consensus development of the kind already applied to the imaging assessment of this joint [3], and are explicitly not a consensus-endorsed reporting standard; the protocol committed us to this framing before any result was known.

Elements 2, 3 and 7 would together resolve most of what could not be established here. Element 3 is the one most easily met and most consistently missed: a single clause recording that a contralateral comparison was not made would remove an ambiguity that at present affects 59.6% of assessments.

For research, the immediate implication is that the relationship between structural TFCC lesion and functional DRUJ instability cannot be recovered from the published record however it is reanalyzed, and requires primary studies that verify the lesion and test the joint in the same patients. For practice, the implication is narrower but not

**Table 6.** Candidate minimum reporting elements and their empirical basis in the present sample

| No. | Element | Empirical basis in the present sample |
|---|---|---|
| 1 | Name the assessment maneuver used | Method unidentifiable in 19.3% of assessments |
| 2 | State the criterion that defines a positive result, operationally | Vague or absent in 61.4% of assessments |
| 3 | State the testing conditions—whether a contralateral comparison was made including when it was not, forearm position, anesthetic state | Contralateral comparison reported in 40.4% of assessments and never explicitly denied; forearm position not reported in 63.2%; anesthetic state not reported in 3.5% |
| 4 | State the time point relative to fixation, and whether the assessment was intraoperative or postoperative | A scheduled postoperative time point could not be identified in 12 of the 32 postoperative assessments, which reported only a mean follow-up interval |
| 5 | State whether the TFCC was structurally verified, by what method, and in how many participants | Not verified in 50% of reports; extent unclear in one of the 15 that did verify |
| 6 | State the numerator and the denominator for any frequency reported | A comparable estimate was available from only 15.8% of assessments |
| 7 | State the definition applied at follow-up separately from the definition applied initially | Both stated in five of 30 reports |
| 8 | State the threshold at which the finding changed management | Explicit threshold in 20% of reports |

TFCC, triangular fibrocartilage complex.

trivial: clinicians reading this literature to decide whether to repair a TFCC or fix an ulnar styloid are frequently not given an operational criterion for instability and, in a smaller subset of reports, are not told which assessment maneuver was used.

### Conclusions

Residual DRUJ instability is assessed frequently after operative fixation of a distal radius fracture but is often incompletely defined. The maneuvers are broadly shared; the threshold that converts a maneuver into a diagnosis is not. Structural lesion and functional instability are not conflated in this literature so much as often not assessed together, and in half of it only one of the two was measured—which is why the relationship between them cannot be recovered from the published record however it is reanalyzed. Until these elements are reported consistently, estimates of residual instability after fixation will remain difficult to compare across studies.

## Article Information

### Author contributions

Conceptualization: SS. Data curation: JHC. Formal analysis: JHC. Investigation: JHC, SS. Methodology: JHC, SS, SL. Project administration: JHC. Supervision: SS. Validation: SS, SL. Visualization: JHC. Writing-original draft: JHC. Writing-review & editing: JHC, SS, SL. All authors read and approved the final manuscript.

### Conflicts of interest

No potential conflict of interest relevant to this article was reported.

### Funding

None.

### Data availability

The review protocol, a dated postregistration amendment log, the procedural record of data locking and agreement calculation, the register of rule-query interpretations, the agreement output and the script that produced it, and the search and deduplication logs are deposited at https://osf.io/5qx3a. On publication the final dataset and both reviewers' locked pre-consensus extraction files will be added, so that every agreement statistic reported here can be recomputed from source.

### Acknowledgments

The protocol was registered on the Open Science Framework (registration DOI 10.17605/OSF.IO/U7AST) and subsequently in PROSPERO (CRD420261460209); the sequence is described under Protocol and registration. This study has not been presented at a conference.

### Disclosure of generative AI use

A large language model—Claude (Anthropic), accessed through the Claude desktop application for Windows, ver. 1.24012.11 (build 09114b); the model release verified on 5 August 2026 was Claude Opus 5—was used at defined points of the review process: title and abstract prescreening with human confirmation of every record; drafting of procedural documents, forms and correspondence; checking of extraction-file independence; assistance with formatting the agreement output; drafting of the written justification accompanying resolved extraction disagreements; and extraction of verbatim sentences from full texts that were presented to the reviewers for the study-design classification. All agreement statistics themselves were computed with the deposited R script and not by the language model. All eligibility, coding and classification decisions were made by the human reviewers. Agreement statistics were calculated before any disagreement was disclosed and were not recalculated after resolution. The points of use, the task given at each, and representative prompts are listed in Supplementary Material 2.

Two source documents supplied as image-only scans were made searchable with ocrmypdf 17.8.1 and Tesseract 5 (English); the original image layers were left unchanged. Four of the 30 included reports are not published in English—three in Czech [33-35] and one in Chinese [30]—and machine-assisted translation was used to read the Czech- and Chinese-language material, as the protocol permits; confirmation by a fluent speaker was not sought. Agreement statistics were computed in R 4.3.3 with the *readxl* package (ver. 1.4.3). No AI-generated image or video is included in this manuscript.

### Supplementary materials

Supplementary materials related to this article can be


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found online at https://doi.org/10.12671/jmt.2026.00290.

**Supplementary Material 1.** Search strategies as executed, and a PRESS 2015 self-assessment.

**Supplementary Material 2.** Use of artificial-intelligence and automation tools.

**Supplementary Table 1.** Report characteristics.

**Supplementary Table 2.** Positive criteria verbatim.

**Supplementary Table 3.** Alignment index inventory.

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# Multiple blocking screws reduce peak stress in a smaller-diameter tibial nail to a level similar to that in a canal-filling nail: a comparative finite element analysis

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**Background:** Cortical contact at the medullary isthmus permits cortical load sharing and constrains nail motion, and is considered important for stable intramedullary nailing. Blocking screws may provide the latter function. This finite element analysis examined whether adding multiple blocking screws to a smaller-diameter nail would reduce peak nail stress to a level similar to that of a canal-filling construct.

**Methods:** Three configurations were modeled in a tibia with a 5-mm diaphyseal defect at the isthmus: an 11-mm canal-filling nail (model A), an 8-mm nail alone (model B), and an 8-mm nail with four 3.5-mm blocking screws positioned circumferentially (model C). An 800-N static axial load was applied at a medial-to-lateral ratio of 3:2 with the distal end fixed. Total deformation and von Mises stresses in bone, nail, and screws were analyzed using a linear elastic, small-deformation formulation.

**Results:** Maximum total deformation was 5.60, 33.33, and 18.82 mm in models A, B, and C, respectively, occurring at the proximal tibia in all models. Peak nail stress in model B was 891.9 MPa, slightly exceeding the assumed 880-MPa yield threshold, whereas peak stresses were similar in models A (272.9 MPa) and C (265.8 MPa). Screw stress was asymmetric: 57.9 and 58.2 MPa in the posterior and medial screws versus 3.2 and 6.8 MPa in the lateral and anterior screws, indicating differential mechanical engagement of the blocking screws.

**Conclusions:** Under the single static loading condition evaluated, four circumferential blocking screws reduced the peak nail stress of a smaller-diameter nail to a level similar to that of a canal-filling nail. Total deformation nevertheless remained approximately 3.4 times that of the canal-filling construct, and peak bone stress differed between constructs. The asymmetric screw-stress distribution was consistent with differential mechanical engagement of the blocking screws. Mechanical equivalence was not established for outcomes other than peak nail stress.

**Level of evidence:** Not applicable.

**Keywords:** Bone screws; Intramedullary fracture fixation; Tibial fractures; Finite element analysis

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## Introduction

### Background

Intramedullary (IM) nailing is the standard of care for tibial diaphyseal fractures [1]. Nail diameter is a principal determinant of construct stiffness, and a canal-filling nail generally yields a stable construct. Donegan et al. [2] defined the optimal nail-to-canal diameter ratio as 0.8 to 0.99, and reported a 4.4-fold increase in nonunion risk for constructs falling outside this range. However, a canal-filling nail cannot always be used in clinical practice. A smaller-diameter nail may be required when the medullary canal is constitutionally narrow or when cortical thinning makes aggressive reaming unsafe. Under these conditions the nail no longer fills the canal, and the residual gap permits nail motion at the fracture site, which has been shown to compromise construct stability in biomechanical testing [3].

Blocking screws, also termed Poller screws, were introduced as an adjunct to IM nailing by Krettek et al. [3,4] in 1999. A blocking screw is inserted into the space between the nail and the endosteal cortex, thereby functionally narrowing the medullary cavity, guiding the nail toward the desired position, and enhancing construct stability [3,5]. Clinical studies have shown that blocking screws are effective for obtaining and maintaining alignment in tibial fractures [4,6].

Blocking screws have been described primarily as an adjunct for fracture reduction—that is, guiding the trajectory of the nail and preventing loss of alignment. A recent finite element (FE) study reported position-dependent changes in construct stiffness and stress distribution when a single Poller screw was placed at various locations and planes in distal tibial fractures [7]. Our previous FE analysis quantified screw-level stress in distal metaphyseal tibial fixation but examined only a single nail diameter and did not address the diaphyseal region [8]. A “fourth-generation” configuration has been proposed in which four blocking screws are placed around the nail in both the anteroposterior (AP) and mediolateral (ML) planes to provide coronal and sagittal stability, yet biomechanical validation of this circumferential configuration has not been reported [9]. Current data are therefore insufficient to fully characterize how stress is distributed across a construct that combines a small-diameter nail with multiple blocking screws, particularly when cortical load sharing across the fracture is removed and the load-constraining role traditionally attributed to isthmic cortical contact (ICC) must be borne entirely by the nail-screw construct.

### Objectives

The purpose of the present study was to analyze the stress distribution and construct stability of a small-diameter IM nail augmented with multiple blocking screws in a tibial diaphyseal bone defect model using FE analysis. The defect was introduced as a controlled worst-case condition that removes cortical load sharing across the fracture, thereby isolating the mechanical contribution of the blocking screws. We hypothesized that adding multiple blocking screws would reduce the peak nail stress of a smaller-diameter construct to a value similar to that of a canal-filling nail, and that the peak stresses developed in the individual screws would be asymmetric under the eccentric loading condition tested.

## Methods

### Ethics statement

The study involved neither human participants nor animals, and institutional review board approval was therefore not required.

### Study design and setting

This was a nonclinical, in silico comparative biomechanical study using FE analysis. Three predefined FE constructs were compared under identical loading and boundary conditions. A 5-mm diaphyseal bone defect was incorporated at the tibial isthmus to remove cortical load sharing across the fracture, thereby allowing the mechanical effects of nail diameter and blocking-screw augmentation to be compared.

The three-dimensional models were constructed and processed using SolidWorks 2019 (Dassault Systèmes) and exported to ANSYS ver. 19.0 (ANSYS Inc.) for final mesh generation and FE analysis.

### Construction of the FE model

#### Model geometry and bone defect

The FE model was based on the three-dimensional computer-aided design (CAD) data of a commercial fourth-generation composite tibia (Sawbones; Pacific Research Labora-


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tories). Fourth-generation composite bones reproduce the axial, bending, and torsional behavior of human long bones with markedly lower interspecimen variability and are regarded as an acceptable substitute for cadaveric specimens in biomechanical studies [10]. An IM nail fixation system for the tibial diaphysis was constructed in three dimensions using SolidWorks 2019 (Dassault Systèmes). The IM nail was modeled based on the Zimmer Natural Nail (Zimmer Biomet). The tibial and implant geometries were adapted from the model used in our previous analysis of distal tibial nailing [8].

Compared with our previous distal tibial model [8], the fracture was relocated to the diaphyseal isthmus and represented by a 5-mm segmental defect. Nail diameter is quoted here as the nominal distal shaft diameter. Consistent with the design of the Zimmer Natural Nail system, the proximal body of both the 8-mm and the 11-mm nail measures 11 mm over its proximal 60 mm, so the two constructs differ in diameter only distal to that segment; the shaft of the smaller nail also tapers slightly and is not of uniform 8-mm diameter along its length. The geometry of the tibia and implants was processed and refined within the SolidWorks platform. The defect was created as a transverse gap centered approximately 180 mm distal to the proximal articular surface and approximately 182 mm proximal to the distal articular surface in a tibia of approximately 367 mm overall length, corresponding to the level of the medullary isthmus. The fracture model was configured in the same CAD software and then exported to ANSYS ver. 19.0 (ANSYS Inc.) for adjustment of implant positioning and final mesh generation.

### Fixation constructs

Three nail fixation constructs were modeled (Fig. 1). Model A consisted of an 11-mm-diameter nail with interlocking screws only. Model B consisted of an 8-mm-diameter nail with interlocking screws only. Model C consisted of the same 8-mm nail with four 3.5-mm blocking screws placed around the bone defect. In all three models, two proximal and two distal 5.0-mm interlocking screws were applied for a total of four interlocking screws.

### Blocking-screw configuration

In model C, two blocking screws were positioned proximal to the defect and two distal, numbered 1 through 4 from proximal to distal. The insertion direction of each blocking screw and its position relative to the nail were as follows: screw 1 was inserted in the ML direction and lay posterior to the nail; screw 2 was inserted in the AP direction and lay lateral to the nail; screw 3 was inserted in the AP direction and lay medial to the nail; and screw 4 was inserted in the ML direction and lay anterior to the nail. This arrangement provided 360-degree support around the nail with the four blocking screws. Screws 1 and 4, both inserted in the ML direction, were positioned 42.75 mm from the adjacent margin of the defect, and screws 2 and 3, both inserted in the AP direction, were positioned 27.75 mm; all distances were measured to the screw axis. The arrangement was therefore symmetric about the defect. Each blocking screw was modeled bicortically, with its length adjusted to the local bone geometry so that the tip protruded approximately 2 mm beyond the far cortex; the individual screw lengths therefore differed between positions.

Each blocking screw was modeled with a minimal clearance from the nail rather than in initial contact, the clearance being small enough that the screw and the nail were effectively adjacent in the undeformed state. Because both the endosteal surface and the nail are curved and non-cylindrical, the clearance between the nail and the endosteal cortex varied around the circumference and along the length of the construct and could not be expressed as a single value; representative cross-sections taken at the level of the defect are shown in Fig. 1B.

## Variables

The construct variables were nail diameter and the presence of blocking-screw augmentation. The outcome variables were total construct deformation and maximum von Mises stress (MPa) in the nail and bone. For model C, maximum von Mises stress in each of the four individual blocking screws was additionally evaluated. Peak nail stress was also expressed as a proportion of the assumed 880-MPa yield threshold of the titanium alloy.

## Finite element analysis

### Material properties

The material properties of the synthetic-bone model were adopted from our previous analysis using the same synthetic bone and implant system (Table 1) [8]. All implants were modeled as titanium alloy (Ti-6Al-4V; ASTM F1472) with linear elastic, homogeneous, and isotropic properties.

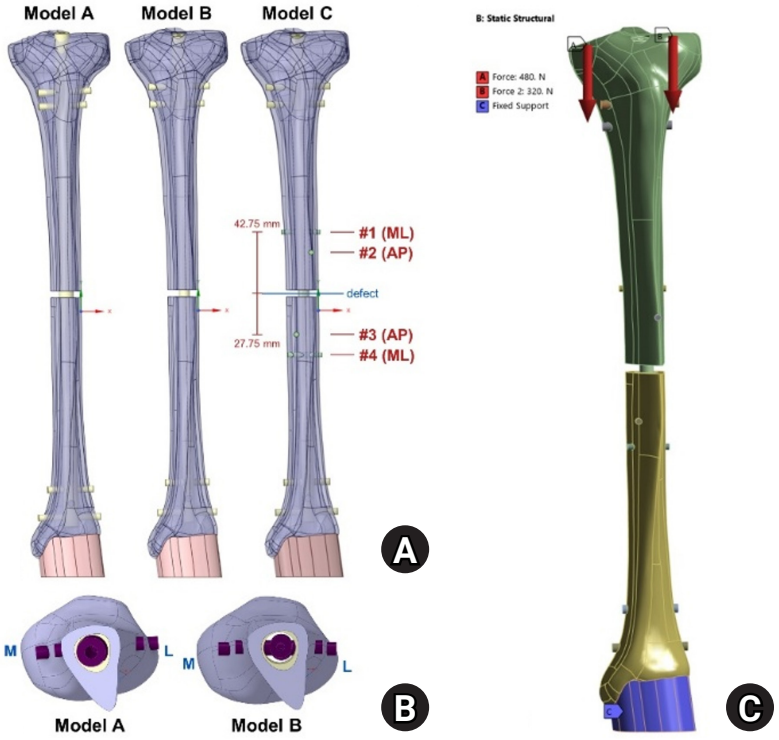



**Fig. 1.** Structural overview of the three finite element models. (A) Anterior views of model A, comprising an 11-mm nail with interlocking screws; model B, comprising an 8-mm nail with interlocking screws; and model C, comprising an 8-mm nail with four blocking screws. In model C, the blocking screws are numbered 1–4 from proximal to distal, and their insertion directions are indicated. Screws 1 and 4 are positioned 42.75 mm from the margin of the defect, and screws 2 and 3 are positioned 27.75 mm, measured to the screw axis. (B) Axial cross-sections of models A and B at the level of the defect, corresponding to the medullary isthmus and viewed from distal to proximal. Cortical bone is shown in light violet, cancellous bone in pale yellow, and the implants in magenta. The screws visible in these sections are interlocking screws. Model C is not shown because its nail is identical to that in model B and its blocking screws lie outside the illustrated plane. (C) Loading configuration consisting of an 800-N static axial load—480 N medially and 320 N laterally—and fixed support at the distal articular surface. ML, mediolateral; AP, anteroposterior; L, lateral; M, medial.

A yield threshold of 880 MPa was assumed for the alloy, adopted from our previous analysis of the same implant system [8]; this is a representative annealed value for Ti-6Al-4V and is used here solely as a reference threshold rather than as a measured property of the implant. Because plasticity was not incorporated into the model, computed stresses exceeding this value indicate that yielding would be expected under the applied load rather than representing physically attainable stresses; peak stresses are accordingly reported both in absolute terms and as a proportion of the assumed threshold, as in earlier FE analyses of screw constructs [11].

**Table 1.** Material properties assigned to the bone and implants

| Material | Density (g/cm$^3$) | Young's modulus (GPa) | Poisson's ratio |
|---|---|---|---|
| Cortical bone | 1.5 | 10.7 | 0.33 |
| Cancellous bone | 0.2 | 0.524 | 0.35 |
| Titanium alloy (nail and screws) | 4.62 | 110 | 0.30 |

Values for cortical bone, cancellous bone, and the titanium alloy were adopted from a previous study [8]. The implants were modeled as Ti-6Al-4V titanium alloy (ASTM F1472). A yield threshold of 880 MPa was assumed, adopted from our previous analysis of the same implant system [8].

### Mesh generation

The bone and the nail were meshed with 10-node quadratic


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tetrahedral elements (SOLID187) at a uniform size of 2.0 mm, and the screws were meshed with 20-node hexahedral elements (SOLID186). Meshing produced 550,005 nodes and 373,729 elements in model A (372,991 tetrahedral and 738 hexahedral), 539,651 nodes and 368,322 elements in model B (367,734 and 588), and 554,950 nodes and 368,518 elements in model C (367,731 and 787). A uniform global element size was applied and no local mesh refinement was introduced at the nail-screw or screw-bone interfaces. This element size was consistent with that adopted in our previous FE analysis of the same nail and synthetic-bone model [8], and further refinement of the mesh produced no meaningful change in the peak von Mises stress within the nail; a separate convergence study at the level of the individual 3.5-mm blocking screws was not performed.

Contact conditions

Contact interactions between the implants and bone were defined according to the mechanical characteristics of each interface. Bonded contact, which presumes complete bonding at the screw-bone interface as assumed in comparable analyses [11], was applied between cortical and cancellous bone, between bone and interlocking screws, and between bone and blocking screws. Frictional contact (coefficient of friction 0.2) was applied between bone and nail, between nail and interlocking screws, and between nail and blocking screws. Bonded contacts permitted neither sliding nor separation. Frictional contacts permitted both sliding, once the interfacial shear limit was exceeded, and separation of the contacting surfaces. Bonded contact was adopted at the screw-bone interfaces because screw threads were not modeled and the analysis was not intended to represent thread purchase or pullout; frictional contact was adopted at the nail-screw and nail-bone interfaces so that the nail could translate and separate relative to the screws and the endosteal surface, thereby allowing the blocking screws to constrain nail motion. The friction coefficient of 0.2 was adopted from previous FE analyses of bone-implant interfaces in the same implant system [8].

Loading and boundary conditions

A static axial load of 800 N was applied to the medial and lateral articular surfaces of the proximal tibia, distributed at a 3:2 medial-to-lateral ratio (480 N medial, 320 N lateral) to approximate the *in vivo* ML load distribution [12]. This ratio lies at the upper end of the 53% to 60% medial share reported at maximum load in instrumented *in vivo* measurements [12]. The distal end of the tibia was set as a fixed support applied to the distal articular surface, removing all six degrees of freedom.

Solution procedure

The problem was solved as a single load step in one substep. Geometric nonlinearity was not enabled, so the analysis corresponds to a small-deformation formulation; the implications of this assumption are addressed in the *Discussion*. All three models converged within the full load step, requiring between 10 and 13 cumulative equilibrium iterations.

### Outcome measurement

Total deformation was computed at the construct level, and the maximum von Mises stress (MPa) was computed separately within the nail domain and the bone domain (cortical and cancellous bone combined) for each model. For model C, the maximum von Mises stress within each individual blocking screw was also computed. Peak nail stress was additionally expressed as a proportion of the assumed 880-MPa yield threshold.

### Statistical methods

Results were compared descriptively across the three deterministic FE models. No inferential statistical testing was performed because the constructs did not represent repeated independent observations. Differences between constructs were reported as absolute values and, where relevant, as relative differences or ratios.

## Results

### Total deformation

Total deformation was greatest in model B (33.33 mm), followed by model C (18.82 mm) and model A (5.60 mm) (Fig. 2). In all three models the maximum value occurred at the proximal tibia, remote from the defect, and corresponded to tilting of the proximal segment about the fixed distal end rather than to displacement at the defect itself. The addition of the four screws to the 8-mm nail reduced its deformation by approximately 44% (model C vs. model B), although the resulting value remained approximately 3.4 times that of model A.

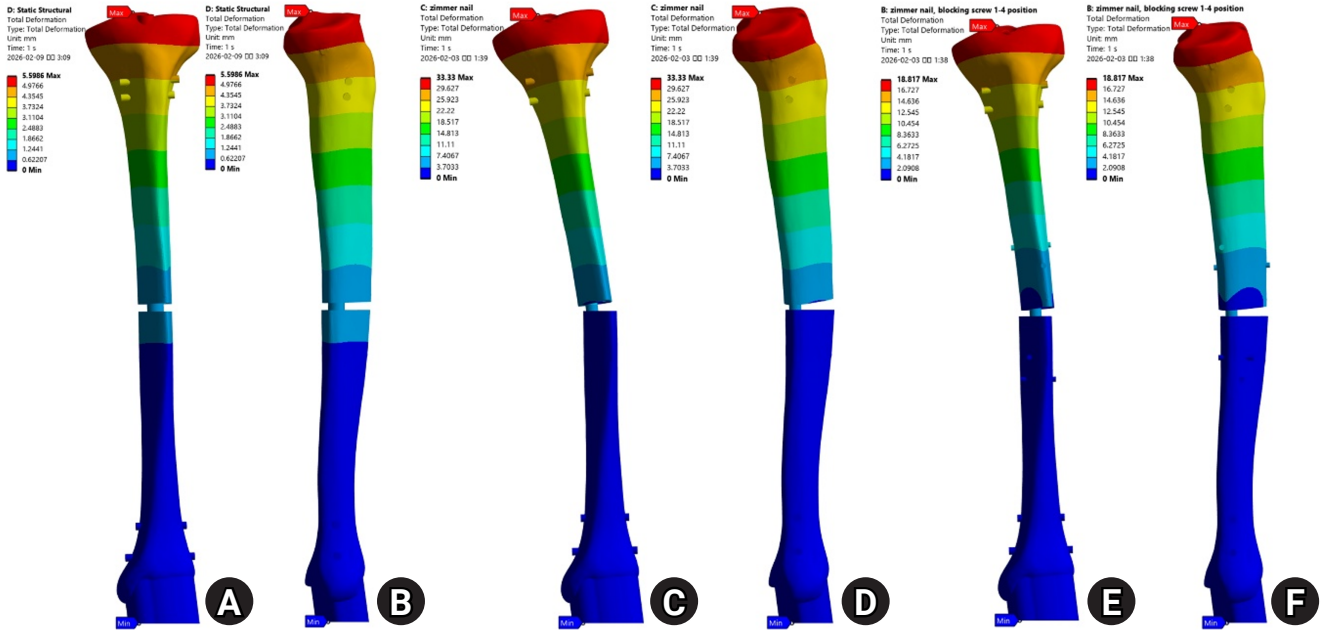



**Fig. 2.** Total deformation under axial loading. Maximum deformation was 5.60 mm in model A (A, B), 33.33 mm in model B (C, D), and 18.82 mm in model C (E, F) and occurred at the proximal tibia in all three models. Anterior views are shown in (A), (C), and (E), and medial views in (B), (D), and (F). The color scale was adjusted separately to the maximum value for each model; therefore, color differences between panels should not be interpreted as differences in absolute deformation.

### Von Mises stress

Maximum nail and bone stresses likewise distinguished the three constructs (Table 2, Figs. 3, 4). Nail stress was 272.9 MPa in model A, 891.9 MPa in model B, and 265.8 MPa in model C, corresponding to 31%, 101%, and 30% of the assumed yield threshold of the alloy. The value in model B was approximately 3.3 times those in models A and C, which were similar to each other (Fig. 4). In model C, the peak nail stress occurred around the defect at the level of the blocking screws (Fig. 5). In model B the computed peak stress reached and slightly exceeded the assumed threshold, by approximately 1.4%. The ranking of peak bone stress did not simply mirror that of peak nail stress: bone stress was lowest in model A (32.4 MPa), intermediate in model C (38.7 MPa), and highest in model B (48.2 MPa) (Fig. 3). The location of the peak also differed: it occurred in the distal tibia in models A and B but in the proximal tibia in model C.

**Table 2.** Maximum von Mises stress (MPa) in each component under axial loading

| Component | Model A | Model B | Model C |
|---|---|---|---|
| Nail | 272.9 | 891.9 | 265.8 |
| Nail stress / assumed yield threshold (%) | 31 | 101 | 30 |
| Bone | 32.4 | 48.2 | 38.7 |

The assumed yield threshold for the titanium alloy is given in Table 1. Model A, 11-mm nail with interlocking screws; model B, 8-mm nail with interlocking screws; model C, 8-mm nail with four blocking screws.

### Stress distribution of individual blocking screws

The peak stresses developed in the four blocking screws in model C were markedly asymmetric (Table 3). The posterior screw proximal to the defect (screw 1, ML orientation) and the medial screw distal to the defect (screw 3, AP orientation) developed the highest peak stresses, at 57.9 MPa and 58.2 MPa, respectively. The lateral screw proximal to the defect (screw 2, AP orientation) and the anterior screw distal to the defect (screw 4, ML orientation) developed substantially lower peak stresses, at 3.2 MPa and 6.8 MPa, respectively. The two higher-stress screws thus developed peak stresses approximately 8.5 to 18 times those of the two lower-stress screws, although all four screws carried non-zero stress. Because peak von Mises stress is a local measure and no force-based output was extracted, these


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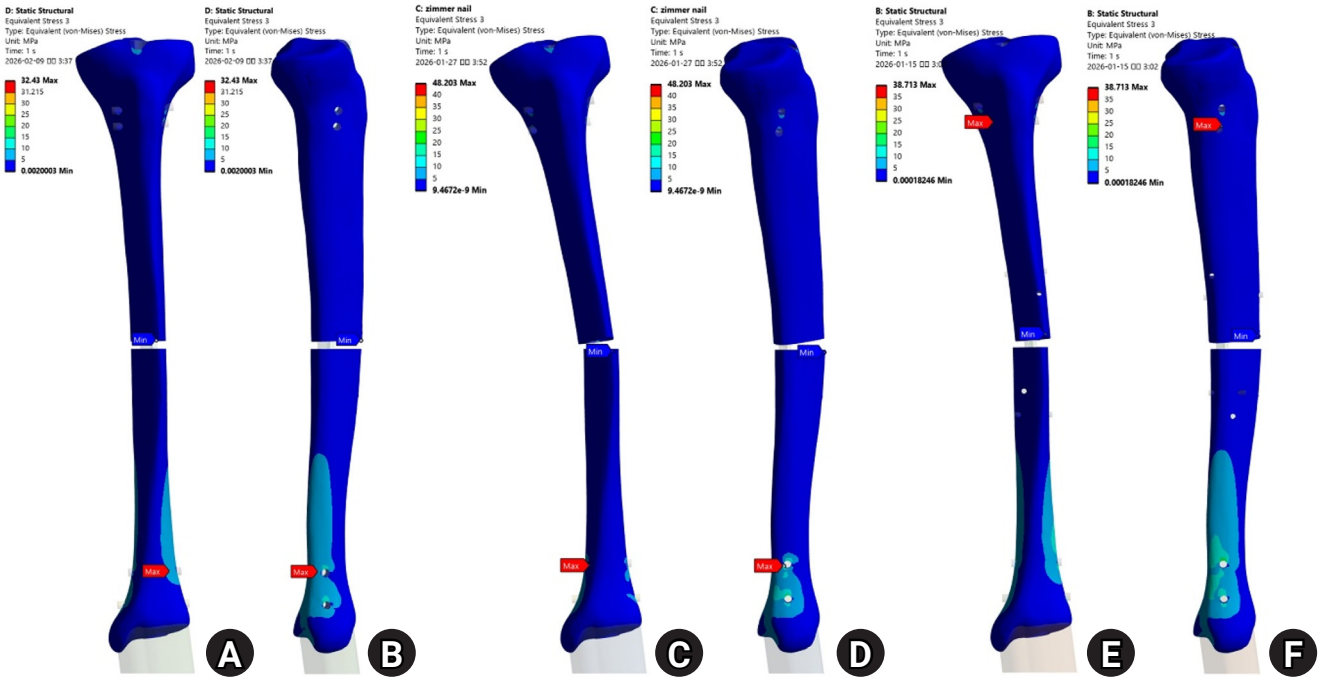



**Fig. 3.** Distribution of von Mises stress in the bone under axial loading, calculated across the entire bone domain. Peak bone stress was 32.4 MPa in model A (A, B), 48.2 MPa in model B (C, D), and 38.7 MPa in model C (E, F). Anterior views are shown in (A), (C), and (E), and medial views in (B), (D), and (F). Contour bands are identical across panels except for the uppermost band, which extends to the model-specific maximum.

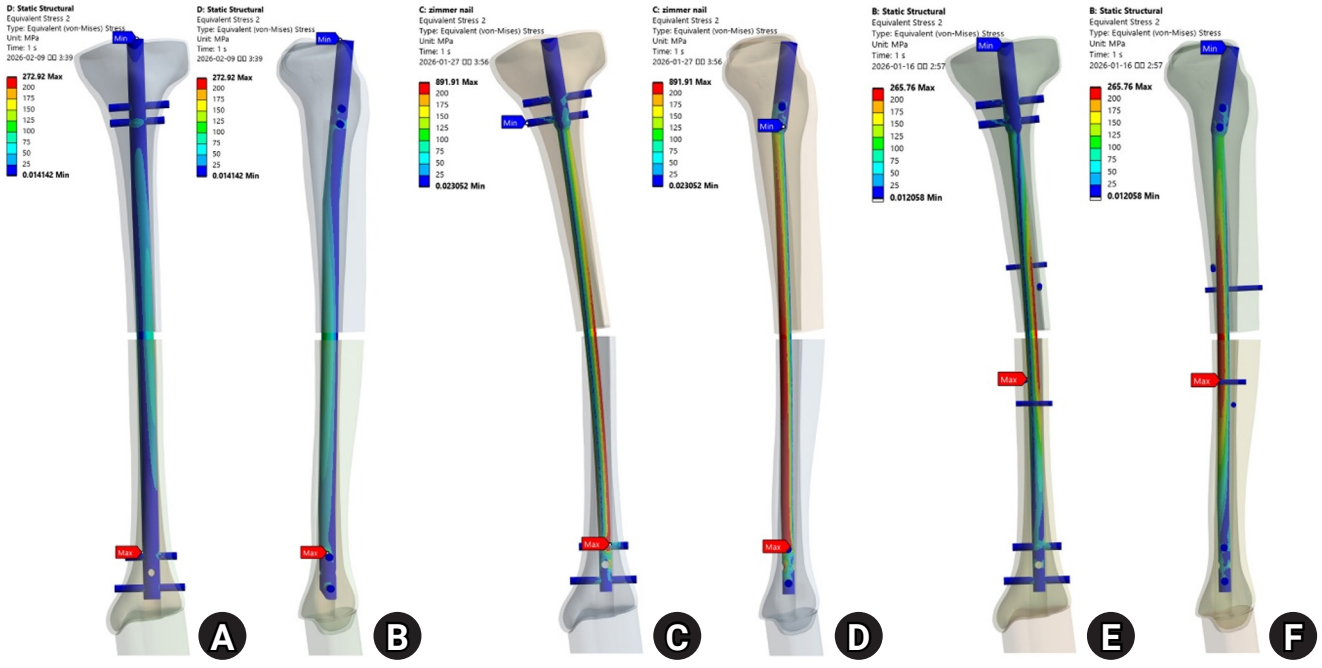



**Fig. 4.** Distribution of von Mises stress in the nail under axial loading. Peak nail stress was 272.9 MPa in model A (A, B), 891.9 MPa in model B (C, D), and 265.8 MPa in model C (E, F). Anterior views are shown in (A), (C), and (E), and medial views in (B), (D), and (F). Model B shows regions of elevated stress along the nail at the defect level, whereas the peak stress magnitude in model C is comparable to that in model A, although in model C the peak occurs at the level of the blocking screws. Contour bands are identical across panels except for the uppermost band, which extends to the model-specific maximum.

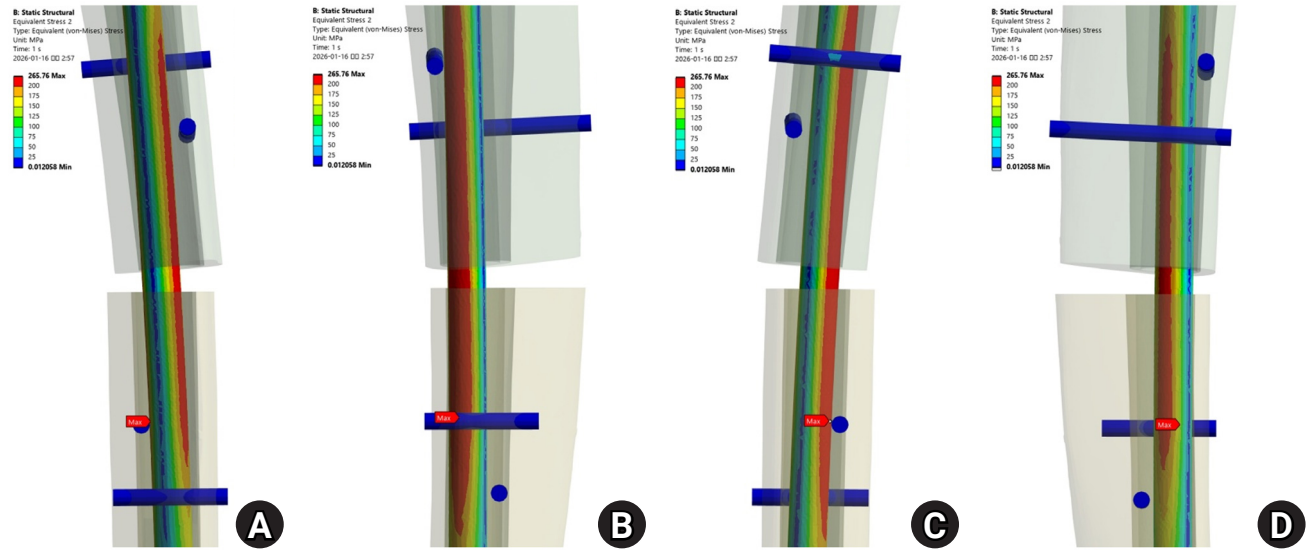



**Fig. 5.** Magnified distribution of von Mises stress around the defect in the model C nail. (A) Anterior, (B) medial, (C) posterior, and (D) lateral views are shown. The maximum nail stress was 265.8 MPa. Peak stresses in the individual blocking screws are reported in Table 3.

**Table 3.** Maximum von Mises stress of individual blocking screws in model C

| Screw no. | Location | Orientation | Position relative to nail | Von Mises stress (MPa) |
|---|---|---|---|---|
| 1 | Proximal | ML | Posterior | 57.9 |
| 2 | Proximal | AP | Lateral | 3.2 |
| 3 | Distal | AP | Medial | 58.2 |
| 4 | Distal | ML | Anterior | 6.8 |

ML, mediolateral; AP, anteroposterior.

values are consistent with relative differences in mechanical engagement among the screws but do not quantify the proportion of the total load transmitted through each screw. The two higher-stress screws lay posterior and medial to the nail on the proximal and distal sides of the defect, respectively, whereas the two lower-stress screws lay lateral and anterior. The differences among the three constructs in total deformation and in peak bone and nail stress are summarized in Fig. 6.

## Discussion

### Key results

In this study, the addition of multiple blocking screws to a smaller-diameter IM nail produced a peak nail stress similar to that of a canal-filling nail and substantially lower than that of the same smaller-diameter nail used without blocking screws. Total deformation was reduced by approximately 44% relative to the unaugmented smaller nail but remained approximately 3.4 times that of the canal-filling construct, and peak bone stress was likewise not equivalent, so the correspondence observed here was confined to peak nail stress and did not extend across the other outcome measures. The peak stresses developed in the individual blocking screws were markedly asymmetric. In a diaphyseal defect model in which cortical load sharing was removed, these findings indicate that multiple blocking screws can reduce the peak nail stress of a smaller-diameter construct toward that of a canal-filling nail under the static loading condition tested; they do not establish overall mechanical equivalence between the two constructs.

### Interpretation/comparison with previous studies

Model B, the smaller nail used alone, was the least stable construct, and its elevated nail stress reflects this vulnerability. The cadaveric literature is consistent with this finding. Penzkofer et al. [13] reported that an 11-mm nail produced significantly less interfragmentary movement than a 9-mm nail and recommended the use of the largest feasible nail diameter. Augat et al. [14] extended this observation, demonstrating that the clearance between nail and canal, rather than the flexibility of the nail itself, was the principal determinant of interfragmentary movement under axial and shear loading. The behavior of model B is consistent with this observation. Model C, by contrast,


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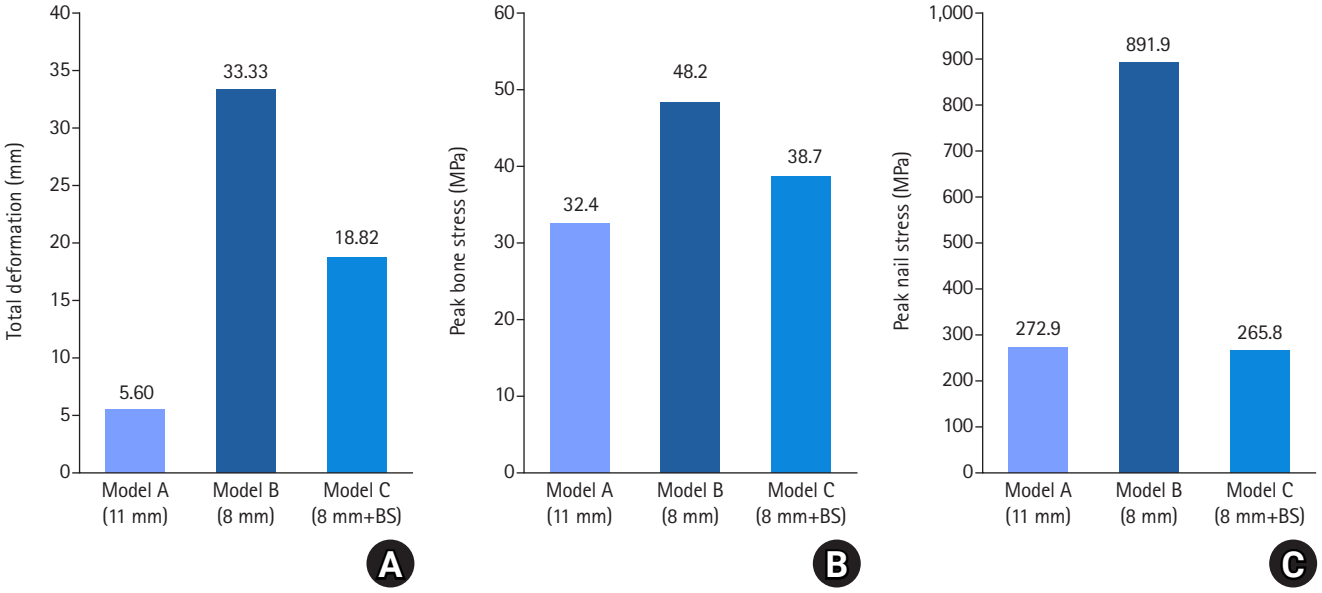



**Fig. 6.** Quantitative comparison of the three models. (A) Total deformation was 5.60, 33.33, and 18.82 mm in models A, B, and C, respectively. (B) Peak bone stress was 32.4, 48.2, and 38.7 MPa, respectively. (C) Peak nail stress was 272.9, 891.9, and 265.8 MPa, respectively. BS, blocking screws.

approached model A in peak nail stress, a result consistent with the screws occupying the nail-cortex gap and constraining nail motion in a manner analogous to ICC in a canal-filling construct [3], although the present analysis did not measure that constraint directly.

The absolute magnitude of the values obtained in model B warrants comment. A total deformation of 33.33 mm is not a displacement that a loaded human tibia would sustain; it follows from the boundary conditions adopted here, in which a 5-mm defect removes all cortical contact across the fracture and the distal tibia is rigidly fixed, so that the entire load path passes through the implant. The maximum deformation occurred at the proximal tibia and represents tilting of the whole proximal segment about the fixed distal end, and it is therefore not a measure of interfragmentary motion at the defect. A further consideration is that the analysis was solved under a small-deformation formulation, without geometric nonlinearity. A deformation of this magnitude lies beyond the range over which that assumption is ordinarily regarded as accurate. Because the deformation predicted for model B is large relative to the assumptions of a small-deformation formulation, the absolute deformation and stress values for this construct should be interpreted with caution. The values reported in this study are therefore intended for relative comparison among constructs modeled under identical assumptions rather than as predictions of *in vivo* displacement or stress. Within this linear-elastic model, the peak nail stress in model B reached 891.9 MPa, approximately 1.4% above the assumed 880-MPa yield threshold [8]. Because the analysis was linear elastic and no plasticity was modeled, a computed stress of this magnitude indicates that yielding would be expected under this loading condition; it is not a demonstration that the implant would fail, and no fatigue analysis was performed. The model also omits the fibula, which *in vivo* carries part of the axial load of the leg, so the entire load path is concentrated through the tibial construct; this further exaggerates the demand placed on the nail in model B and reinforces the view that these values are worst-case and comparative rather than predictive. Within the present model, the unsupported 8-mm nail reached the assumed yield threshold, whereas the addition of four blocking screws reduced peak nail stress to approximately 30% of that threshold. Experimental observation is consistent with this reading: in a synthetic-tibia model fixed with a 9-mm nail, all constructs survived 10,000 ML loading cycles without hardware deformation, but under a subsequent 350-N failure test nail loosening and nail bending occurred exclusively in specimens without blocking screws [15].

Blocking screws have traditionally been regarded as an adjunct for fracture reduction [4-6]. The present findings suggest an additional mechanical role: following nail

fixation, the blocking screws can become mechanically engaged, and their presence was associated with a reduction in the peak stress developed in the nail. Krettek et al. [3], in cadaveric metaphyseal specimens loaded in ML bending, reported a 25%–57% reduction in construct deformation after blocking screw insertion. Zhang et al. [15], testing synthetic tibiae under ML loading, likewise reported reductions of 26.2% and 28.9% in maximum construct displacement with conventional and modified blocking screws, respectively. The present study examined a different configuration—a diaphyseal defect under axial loading, with nail stress as the primary outcome—and observed a comparable direction of effect. The configuration is itself recent: a "fourth-generation" arrangement positions four screws circumferentially to stabilize both the coronal and sagittal planes on either side of the fracture [9], yet it had not been characterized mechanically. The present data provide a first characterization of this configuration under a single static loading condition, in which the four-screw construct reached a peak nail stress similar to that of a canal-filling nail. The arrangement examined here is an idealized biomechanical one; its anatomical feasibility, the additional operative burden it imposes, and any clinical benefit were not assessed. On this basis, the screws appear to contribute mechanically beyond their role as a reduction adjunct, which may partly offset the loss of the load-constraining role attributed to ICC.

Peak stress among the four screws was markedly uneven. Under the 3:2 medial-to-lateral load, screw 1 (posterior) and screw 3 (medial) developed the highest peak stresses, whereas screw 2 (lateral) and screw 4 (anterior) developed much lower values. This pattern is consistent with a posteromedial toggle of the nail driven by the eccentric load, the screws opposing that displacement being the most strongly engaged. The classical recommendation to place a blocking screw on the concave side of the deformity [5] is thus consistent with the present peak-stress distribution. Because displacement vectors and contact-pressure distributions were not extracted, however, this mechanism is presented as a model-based inference rather than as a directly demonstrated finding. This does not render screws 2 and 4 redundant. The model was loaded in a single static axial direction, whereas *in vivo* loading varies in direction and magnitude throughout the gait cycle [12]; when the direction of toggle changes, a screw that was minimally engaged under the present condition may become the principal load-bearing element. This is a hypothesis that the present analysis does not test, since only one loading direction was examined, and the four-direction arrangement should not be regarded as a generally validated default on the basis of these data.

Bone stress in model C (38.7 MPa) was intermediate between model A (32.4 MPa) and model B (48.2 MPa), indicating that the three constructs produced different local stress distributions within the bone. Because only peak von Mises stress was extracted and no contact or reaction forces were computed, these values should not be interpreted as direct measures of load sharing. Whether the intermediate bone stress observed in model C represents a biologically favorable mechanical environment cannot be determined from the present model. As the applied load was static and axial, the implications of these differences for fracture healing remain to be established.

The present analysis further extends earlier screw-level work. A single-screw FE analysis addressed the position dependence of one Poller screw but not the distribution among multiple screws [7], and a previous distal tibial analysis reported an approximately 20%–27% reduction in stress around the distal interlocking screws with blocking screws [8]. A recent report on lower limb extra-isthmic fractures, which combined a meta-analysis with a FE analysis of the distal tibia, described the opposite direction of effect on implant stress in its FE component, which rose from 86.7 to 120.1 MPa when a Poller screw was added, while displacement at the fracture site fell by 54.9% [16]. The discrepancy is instructive. In that model the unaugmented construct was already stable, with fracture-site displacement of only 0.11 mm, so an additional screw introduced a further load path and raised implant stress. In the present model the unaugmented smaller nail was grossly overloaded across a defect, and the addition of the screws was associated with a lower peak nail stress rather than a higher one. The direction in which blocking screws shift implant stress therefore appears to depend on how far the baseline construct sits from mechanical failure, whereas the displacement measures reported were reduced in every case, although these were not the same quantity: global construct deformation in the present model and fracture-site displacement in the extra-isthmic analysis [16]. The pattern of stress redistribution therefore appears to reflect the loading condition,


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the screw orientation, and the stability of the baseline construct. In a systematic review of 13 studies comprising 371 patients, Tennyson et al. [17] reported low pooled proportions of nonunion (4%) and coronal malunion (5%) after blocking-screw augmentation, lower than the rates reported in the literature for nailing alone. The meta-analytic component of the extra-isthmic report cited above [16], pooling five comparative cohorts with 413 patients, found a higher union rate with Poller screws (odds ratio 2.48; 95% confidence interval 1.13–5.46) and fewer secondary procedures. The present study offers one possible mechanical basis for these observations. That relationship is hypothesis generating and does not establish a causal link between the modeled stress environment and clinical union.

## Limitations

This study has several limitations. First, although the use of a fourth-generation Sawbones composite tibia ensured high reproducibility [10], it does not fully capture the density variation and microstructure of human bone. Second, only a static axial load was applied; rotational and bending loads, as well as the dynamic load variation across the gait cycle, were not considered, and the 800-N load applied here is well below the peak tibial load recorded during gait and stair activity [12]. Third, screw threads were not modeled, so pullout and local micromotion at the screw-bone interface could not be represented; screw-bone contact was idealized as fully bonded, which overestimates the constraint at that interface. Fourth, the 5-mm defect used in this study is relatively small, and results may differ for larger defects. On the other hand, the presence of a defect itself eliminates cortical bridging across the fracture and thus represents a worst-case condition for the nail-screw construct, under which the correspondence in peak nail stress between the blocking-screw-augmented smaller nail and the canal-filling construct observed here was still preserved. Fifth, the analysis was based on a single tibial geometry, and the effect of anatomic variation on the results was not assessed. Sixth, the model was not validated against experimental mechanical testing, and no cadaveric or synthetic-bone measurements were available for direct comparison; the results should accordingly be read as relative comparisons among constructs sharing identical assumptions rather than as absolute predictions of construct performance. Protocols suitable for such validation have been described for synthetic tibiae under cyclic loading [15]. Seventh, the analysis used a small-deformation formulation and did not enable geometric nonlinearity; therefore, the absolute deformation and stress values, particularly for model B, should be interpreted with caution and regarded as comparative rather than as absolute predictions of construct behavior. Eighth, total deformation is a global construct-level measure and is not equivalent to interfragmentary motion at the defect; relative displacement between the fragments was not extracted. Ninth, the peak von Mises stresses reported for the individual blocking screws are local stress measures that may depend on element size and the contact assumptions adopted, and no convergence study was performed at the level of the individual screws. Tenth, peak von Mises stress is not a direct measure of load sharing; no contact or reaction forces were computed, so the proportion of load transmitted through each screw was not quantified. Eleventh, the fibula was not included in the model, so the load sharing that it provides *in vivo* was not represented, and the demand on the tibial construct is correspondingly overstated.

## Implications

The present findings have practical implications when a smaller-diameter nail is required because of a narrow medullary canal or cortical thinning. Augmenting a smaller-diameter nail with multiple blocking screws lowered the modeled peak nail stress toward that of a canal-filling nail, providing a limited biomechanical rationale for this combination when a canal-filling nail cannot be used; it does not establish that the two constructs behave equivalently, since deformation and bone stress differed. The asymmetric peak stress among the four screws indicates that each screw's mechanical role is shaped by the direction of nail displacement rather than by its presence alone; since loading direction may vary with fracture configuration and weight-bearing pattern, these findings may complement existing anatomical and technical guidance on blocking screw placement [18] and may inform surgical planning, although further validation under dynamic and multidirectional loading is needed before specific placement recommendations can be made.

## Conclusions

Under the single static loading condition tested, the ad-

dition of multiple blocking screws to a smaller-diameter IM nail reduced the modeled peak nail stress to a value similar to that of a canal-filling nail in a tibial diaphyseal bone defect model, although total deformation remained approximately 3.4 times that of the canal-filling construct and peak bone stress was intermediate rather than equivalent. Peak stress among the blocking screws was asymmetric, with the screws opposing nail toggle developing the highest values. These results support a mechanical role for blocking screws beyond their use as an adjunct for fracture reduction and suggest that, under the modeled conditions, they may partly offset the loss of the load-constraining role attributed to ICC. Equivalence in stiffness, interfragmentary stability, fatigue performance, or clinical outcome was not evaluated.

## Article Information

### Author contributions

Conceptualization: GHJ. Methodology: SLJ, GHJ. Software: SLJ, GHJ. Validation: SLJ. Investigation: JA, SLJ, GHJ. Formal analysis: JA, SLJ, GHJ. Data curation: JA, SLJ. Visualization: JA, SLJ, GHJ. Supervision: GHJ. Project administration: GHJ. Writing–original draft: JA. Writing–review & editing: JA, GHJ. All authors read and approved the final manuscript.

### Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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### Data availability

All data relevant to this study are presented in the tables.

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### Supplementary materials

None.

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# Percutaneous Kirschner-wire fixation followed by an opencast to permit protected daily and sports activities in patients with tendinous mallet finger: a case series at a tertiary hospital in Korea

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**Background:** Dong-A University Hospital's protocol for tendinous mallet finger requires 12 weeks of continuous full-time distal interphalangeal (DIP) joint splinting, which may restrict activities and complicate hygiene. This study evaluated the feasibility, short-term safety, and 6-month clinical outcomes of buried Kirschner-wire fixation followed by opencast application.

**Methods:** This retrospective case series screened 36 patients with mallet finger between January 2024 and October 2025. Twelve met the exclusion criteria, leaving 24 eligible patients; eight elected nonoperative treatment, and 16 chose surgery for acute closed tendinous mallet finger and constituted the study cohort. The DIP joint was fixed in approximately 15° of hyperextension using one or two buried 1.1-mm Kirschner wires. An opencast was applied at 1 week. The wires were routinely removed and active motion was initiated at 8 weeks, followed by a removable brace during outdoor or sports activities for 4 weeks. Outcomes were evaluated at 6 months.

**Results:** The mean preoperative extension lag was 30.0°. At 6 months, the mean residual extension lag was 1.9°, no flexion loss was observed, and Crawford outcomes were excellent in 62.5% and good in 37.5%. Two superficial pin-site infections resolved with oral antibiotics and local wound care. A separate case of wire loosening with painful subcutaneous prominence was managed with an aluminum splint. All patients resumed daily activities and showering at 1 week, when protected sports were also permitted; exact return dates and activity intensity were not recorded.

**Conclusions:** Buried Kirschner-wire fixation followed by opencast application may be an option for selected patients who wish to avoid prolonged full-time splinting. The protocol permitted protected activities from week 1 and active DIP motion from week 8; these findings support its feasibility but do not establish earlier return to unrestricted activity.

**Level of evidence:** IV.

**Keywords:** Mallet finger; Extensor tendons; Kirschner wires; Splints; Sports

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## Introduction

### Background/rationale

Mallet finger is an injury characterized by disruption of the terminal extensor tendon at the distal interphalangeal (DIP) joint, resulting in loss of active extension. Mallet finger is classified as bony or tendinous depending on whether an avulsion fracture fragment is present [1,2]. Tendinous mallet finger falls within Doyle type I and typ-

ically results from a sudden flexion force applied to an extended fingertip. It is commonly encountered among individuals participating in sports, particularly ball sports [1,3,4].

The standard treatment for tendinous mallet finger is nonoperative management with continuous immobilization of the DIP joint in extension or slight hyperextension [5,6]. In our institutional protocol, continuous full-time DIP joint splinting is maintained for 12 weeks to allow the terminal extensor tendon to heal through scar formation and acquire sufficient tensile strength. Several studies and systematic reviews have reported no significant difference in final clinical outcomes between nonoperative and operative treatment of mallet finger injuries [7,8]. Considerable variation in treatment strategies among countries and surgeons has also been noted [9]. Accordingly, the rationale for surgery in tendinous mallet finger lies not in achieving superior final clinical outcomes or less residual extension lag, but in reducing the burden of treatment and allowing earlier functional participation. A treatment that maintains healing while permitting hygiene, routine hand use, and protected sports participation may improve convenience, satisfaction, and quality of life during the treatment period.

The problems associated with prolonged splinting can be summarized in three points. First, treatment success depends entirely on patient compliance [6]. If a patient removes the splint for cleaning or because of discomfort and allows the DIP joint to flex, the healing terminal tendon is stretched again, effectively requiring treatment to restart from the beginning. Second, continuous splint wear may cause skin maceration, malodor, contact dermatitis, and even skin ulceration. Stern and Kastrup [10] reported a 45% complication rate among 84 splinted digits; most complications were skin-related and transient. Restrictions on hand washing, routine hand use, and sports participation can delay return to usual activities and reduce patient satisfaction and quality of life during treatment. Third, as swelling subsides, the splint may loosen and the DIP joint immobilization angle may change subtly; consequently, residual extension lag can be difficult to control completely even in compliant patients [11].

Importantly, surgeons' concerns do not always align with patients' priorities. Surgeons tend to focus on a few degrees of residual extension lag, whereas patients may place greater importance on the burden of prolonged full-time splinting, including hygiene problems, inability to use the hand normally, and restrictions on sports. When final clinical outcomes are expected to be broadly comparable, these differences in the treatment experience should be considered during shared decision-making.

We therefore adapted the technique of subcutaneous Kirschner wire (K-wire) burial and opencast immobilization, which we previously reported for bony mallet finger, to the treatment of tendinous mallet finger [12].

### Objectives

The purpose of this study was to evaluate the feasibility and short-term safety of this treatment protocol and to report the 6-month clinical outcomes and functional progression permitted during treatment in a consecutive surgical series. We hypothesized that, without necessarily improving the final clinical result compared with nonoperative treatment, the protocol could reduce the restrictions associated with our 12-week institutional nonoperative splinting protocol and facilitate earlier return to daily and sports activities.

## Methods

### Ethics statement

This study was approved by the Institutional Review Board of Dong-A University Hospital (No. DAUHIRB-26-205). Informed consent was obtained from all study participants. Written informed consent for publication of identifiable clinical photographs was obtained from the patients whose images are included in this article.

### Study design

This study was a retrospective, consecutive case series.

### Setting

Between January 2024 and October 2025, 36 patients with mallet finger were screened for eligibility at Dong-A University Hospital.

### Surgical technique

All procedures were performed under digital block anesthesia with mobile fluoroscopic guidance. Prophylactic intravenous antibiotics were administered before K-wire insertion. After sterile preparation, a rubber tourniquet fashioned from the finger of a surgical glove was applied.

The DIP joint was manually reduced, and the operating surgeon used a handheld goniometer to position it at a target of approximately 15° of hyperextension, using the longitudinal axes of the middle and distal phalanges as reference lines. The angle was rounded to the nearest 5° and was subsequently confirmed on lateral fluoroscopic imaging. The achieved angle was not recorded separately for each patient, and no serial angular measurement was performed at K-wire removal. The target position was selected to compensate, as far as possible, for the residual extension lag that commonly develops during healing. Care was taken to avoid excessive hyperextension because perfusion of the dorsal skin over the DIP joint decreases as hyperextension increases, potentially causing dorsal skin necrosis.

A 1.1-mm K-wire was then inserted centrally along the longitudinal axis from the tip of the distal phalanx, passed across the DIP joint, and advanced to the proximal one-third of the middle phalanx. One K-wire was used in four patients, whereas two K-wires were used in 12 patients. A second wire was added when rotational instability was a concern or fixation with a single wire was considered insufficient, using a symmetric configuration on the anteroposterior view [13]. Joint congruity and maintenance of approximately 15° of hyperextension were reconfirmed on anteroposterior and lateral fluoroscopic images.

Using a dedicated cutter (Fig. 1), each K-wire was cut sufficiently short to allow burial beneath the skin [12]. The insertion trajectory was kept away from the nail bed and nail matrix. The skin over the wire insertion site was closed with 5-0 nylon sutures. After release of the tourniquet and before completion of the procedure, the operating surgeon, an orthopedic hand specialist, inspected the nail bed and eponychium and performed a capillary refill test of the fingertip. Intact skin circulation was confirmed in all cases. To accommodate postoperative swelling and protect the wound, temporary immobilization with an aluminum splint extending to the proximal interphalangeal joint was applied. An additional aluminum splint was fabricated in the operating room and provided to each patient in case wire loosening or loss of protection occurred.

### Postoperative management

At the first outpatient visit 1 week postoperatively, the sutures were removed and tissue adhesive was applied. The temporary splint was then replaced with a custom-fitted opencast immobilizing only the DIP joint while leaving the proximal interphalangeal joint free [12]. The opencast was fabricated and applied by an experienced cast technician under physician supervision. Its exact material composition could not be specified because the manufacturer did not disclose the proprietary formulation. Showering and protected daily activities were permitted from that time. Running and protected sports requiring hand use, including golf, basketball, and tennis, were also permitted with the opencast in place. Because swelling reduction or external impact could result in wire or construct loosening, patients were instructed to reapply the spare aluminum splint and present immediately to the outpatient clinic or emergency department if loosening was suspected. Patients were followed at 1-week intervals.

K-wire removal was routinely scheduled at 8 weeks postoperatively. Removal was performed without hospitalization at the ambulatory surgery center under local anesthesia, required approximately 5 minutes, and cost ap-

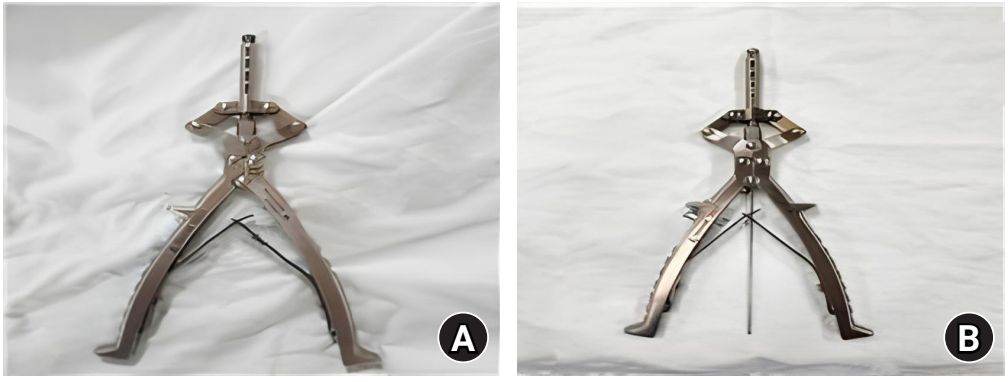



**Fig. 1.** Dedicated Kirschner-wire cutter without (A) and with (B) a Kirschner wire loaded. The cutter allows the wire to be cut close to the bone surface for burial beneath the skin.


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proximately 120,000 Korean won. A short course of oral antibiotics was prescribed after K-wire removal; no additional intravenous antibiotics were administered for the removal procedure. Tissue adhesive was applied to the wire-removal sites, and active DIP joint motion was permitted immediately thereafter. During the subsequent 4 weeks, until 12 weeks postoperatively, continuous immobilization was no longer required for routine daily activities; patients wore a removable mallet brace only during outdoor or sports activities. From 12 weeks onward, unrestricted activities were permitted. When wire loosening or painful subcutaneous prominence was suspected, the spare aluminum splint was applied and the patient was reassessed promptly.

### Participants

Doyle type I injury was defined as a closed or blunt injury with loss of terminal extensor tendon continuity, with or without a small avulsion fracture [1]. In this study, tendinous mallet finger was defined as a Doyle type I injury with loss of active DIP joint extension and without an avulsion fragment on plain radiographs. Exclusion criteria were an open injury, bony mallet finger with an avulsion fragment, presentation more than 2 weeks after injury, poor dorsal skin condition over the DIP joint, a high risk of delayed wound healing such as diabetes mellitus, and follow-up of less than 6 months. Nonoperative treatment consisting of continuous full-time DIP extension splinting for 12 weeks was recommended to all 24 eligible patients. Surgery was indicated only for acute injuries treated within 2 weeks of injury.

### Variables

Extension lag was defined as the degree to which the DIP joint failed to reach the neutral position during active extension, and flexion loss was measured in comparison with the contralateral unaffected digit [11]. Outcomes were graded according to the Crawford criteria [14]. Resumption of daily activities was defined as return to routine self-care and occupational hand use, including washing, dressing, eating, and work duties. Showering was assessed separately, with patients advised to avoid soaking or direct friction around the healing wound. Pin-site infection, pin protrusion, wire loosening, nail deformity, and dorsal skin complications were also assessed.

### Data sources/measurement

Preoperative extension lag and DIP joint range of motion at follow-up were measured directly with a handheld goniometer by the operating surgeon, an orthopedic hand specialist. Measurements were rounded to the nearest 5° because finer precision was not considered clinically reliable. Residual pain was measured at 6 months using a visual analog scale (VAS), with scores ranging from 0 (no pain) to 10 (worst pain imaginable). Permission to resume sports and subsequent sports participation were assessed by direct patient questioning during follow-up visits; however, the exact date and intensity of return to each sport were not systematically recorded. All angular measurements reported in this study were performed directly by the operating surgeon.

### Bias

To minimize selection bias, all consecutive patients who underwent surgery during the study period were included without selective omission, although angular measurements by the operating surgeon without an independent assessor may have introduced observer bias.

### Study size

No a priori sample size calculation was performed because this was a descriptive case series; the study size was determined by all consecutive eligible patients who chose surgical treatment between January 2024 and October 2025.

### Statistical methods

Because this was a small, single-arm case series, only descriptive analyses were performed. Continuous variables were summarized as means and ranges, and categorical variables as numbers and percentages. No inferential statistical testing was performed.

## Results

### Participants

Twelve patients were excluded: four because of a bony avulsion fragment, four because they presented more than 2 weeks after injury, two because follow-up was less than 6 months (both treated nonoperatively), one because of an open injury, and one because of diabetes mellitus with a high risk of delayed wound healing. This left 24 eligible

patients. Eight patients declined surgery and elected nonoperative treatment, whereas 16 chose surgical treatment and constituted a consecutive surgical series; no surgically treated patient was selectively omitted. None of the 16 surgical patients underwent a trial of splint treatment before surgery because surgery was performed within 1–2 days after presentation. The reasons for choosing surgery were an unwillingness to undergo 12 weeks of full-time splinting in four patients, a desire for early return to sports in eight, and the need for continued hand use at work in four. The mean injury-to-surgery interval was approximately 7 days (maximum, 13 days). The mean patient age was 49 years (range, 36–74 years); 12 patients were male and four were female. The index finger was affected in four patients, the middle finger in six, the ring finger in two, and the little finger in four. All injuries were sustained during sports: soccer in eight patients, basketball in four, and dodgeball in four. The dominant hand was involved in 14 patients and the nondominant hand in two.

The preoperative mean extension lag was 30.0° (range, 15°–45°). Before surgery, the deformity in all 16 patients was passively correctable to the neutral position. One K-wire was used in four patients and two K-wires in 12. All patients completed the scheduled follow-up through 12 weeks and underwent final clinical assessment 6 months postoperatively; none was lost before the 6-month assessment.

### Main results

All patients resumed routine daily activities and showering with wound precautions 1 week postoperatively. With the opencast in place, running and sports requiring hand use, including golf, basketball, and tennis, were permitted from the same time point. Subsequent participation in sports was confirmed by direct patient questioning at follow-up, but the exact return date and intensity were not systematically recorded. Active DIP joint motion was initiated after routine K-wire removal at 8 weeks. During the subsequent period through postoperative week 12, patients wore a removable mallet brace only during outdoor or sports activities. At the 6-month evaluation, the VAS pain score was 0 in all 16 patients. The mean residual extension lag was 1.9° (range, 0°–5°), and no patient had flexion loss compared with the contralateral digit. According to the Crawford criteria [14], outcomes were excellent in 10 patients (62.5%) and good in six (37.5%); there were no fair or poor outcomes (Table 1).

Two patients developed superficial pin-site infections; both resolved with oral antibiotics and local wound care without additional surgery. One separate patient developed wire loosening with painful subcutaneous prominence, which was managed with the spare aluminum splint and close follow-up until routine wire removal at 8 weeks; this event did not overlap with either pin-site in-

**Table 1.** Summary of the 16 cases

| Case no. | Sex | Age (yr) | Preoperative extension lag (°) | Residual extension lag (°)[a] | Flexion loss (°)[a] | Outcome[b] |
|---|---|---|---|---|---|---|
| 1 | Male | 36 | 15 | 5 | 0 | Good |
| 2 | Male | 38 | 20 | 0 | 0 | Excellent |
| 3 | Male | 40 | 20 | 5 | 0 | Good |
| 4 | Female | 42 | 25 | 0 | 0 | Excellent |
| 5 | Male | 44 | 25 | 0 | 0 | Excellent |
| 6 | Male | 45 | 25 | 5 | 0 | Good |
| 7 | Female | 46 | 30 | 0 | 0 | Excellent |
| 8 | Male | 47 | 30 | 0 | 0 | Excellent |
| 9 | Male | 48 | 30 | 5 | 0 | Good |
| 10 | Male | 49 | 30 | 0 | 0 | Excellent |
| 11 | Male | 50 | 35 | 0 | 0 | Excellent |
| 12 | Male | 51 | 35 | 5 | 0 | Good |
| 13 | Male | 52 | 35 | 0 | 0 | Excellent |
| 14 | Male | 53 | 40 | 0 | 0 | Excellent |
| 15 | Female | 69 | 40 | 5 | 0 | Good |
| 16 | Female | 74 | 45 | 0 | 0 | Excellent |

[a]Measured at the 6-month follow-up. [b]Graded according to the Crawford evaluation criteria [14].


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fection. After tourniquet release at the end of surgery, the nail bed and eponychium were inspected and capillary refill was confirmed to be intact in all patients. No dorsal skin necrosis, permanent or transient nail deformity, unplanned reoperation, or other major complication was observed.

### Representative case

A 53-year-old man presented 5 days after trauma to the left little finger with inability to extend the DIP joint. Plain radiographs showed no avulsion fragment, and physical examination confirmed acute tendinous mallet finger with loss of active extension of the DIP joint (Fig. 2). Under digital block anesthesia, the DIP joint was reduced in approximately 15° of hyperextension, with the angle directly measured by the operating surgeon, and a K-wire was inserted from the fingertip across the DIP joint. The wire was cut short using the dedicated cutter, buried beneath the skin, and the insertion site was closed with 5-0 nylon sutures (Fig. 3). After tourniquet release, the nail bed and eponychium were inspected and normal capillary refill was confirmed before completion of the procedure. At 1 week postoperatively, the sutures were removed and an opencast was applied; showering, daily activities, and protected sports activities were permitted (Fig. 4). At 8 weeks, the K-wire was removed at the ambulatory surgery center under local anesthesia (Fig. 5), and active DIP joint motion was initiated. Until 12 weeks postoperatively, the patient wore a removable mallet brace only during outdoor or sports activities (Fig. 6).

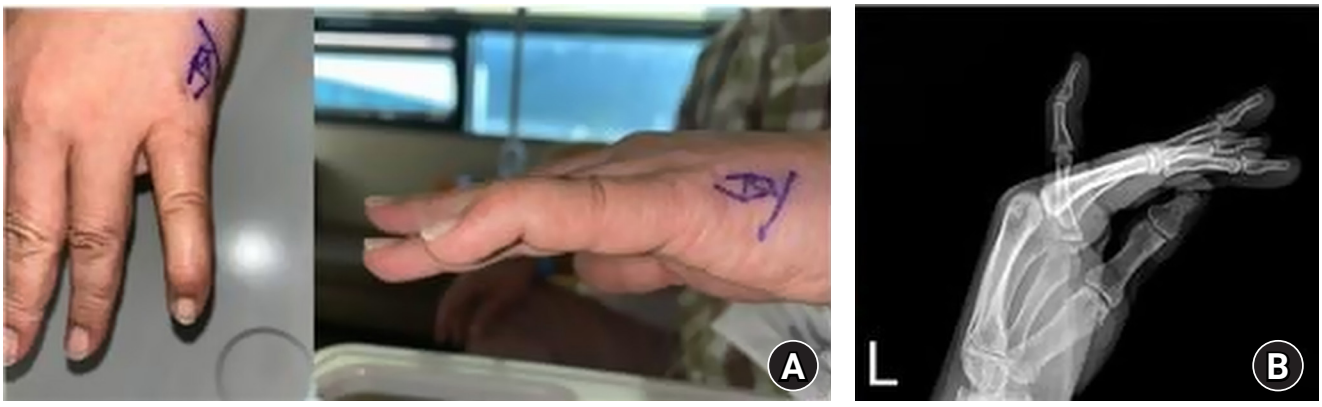



**Fig. 2.** Representative preoperative clinical photographs (A) and radiograph (B) showing loss of active extension of the distal interphalangeal joint of the left little finger.

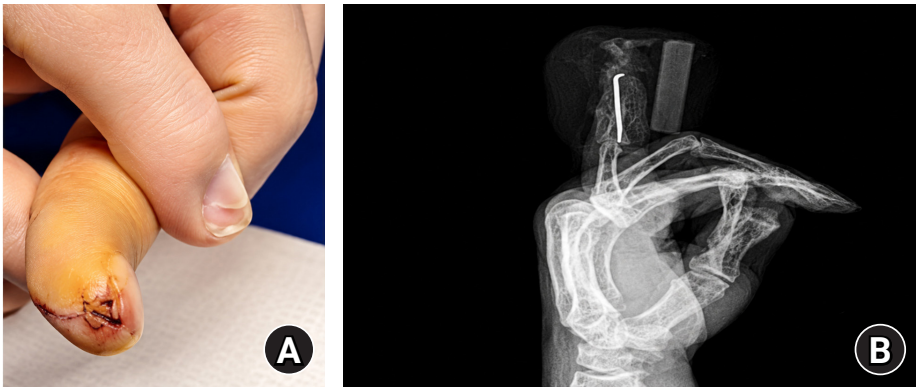



**Fig. 3.** (A) The Kirschner wire was buried beneath the skin, and the overlying insertion site was closed with 5-0 nylon sutures. (B) Immediate postoperative radiograph. The distal interphalangeal joint was fixed in approximately 15° of hyperextension using a Kirschner wire passed from the fingertip across the joint and into the middle phalanx.



**Fig. 4.** Opencast applied at the first outpatient visit, 1 week postoperatively. Only the distal interphalangeal joint was immobilized, permitting showering and protected daily and sports activities.



**Fig. 5.** Radiograph obtained 8 weeks postoperatively, immediately after removal of the Kirschner wire.



**Fig. 6.** Removable mallet finger brace applied after Kirschner-wire removal and worn until 12 weeks postoperatively.

## Discussion

### Key results

In this study, we evaluated the feasibility and short-term safety of treating acute tendinous mallet finger within 2 weeks of injury using percutaneous K-wire fixation of the DIP joint in approximately 15° of hyperextension, together with the 6-month clinical outcomes. Of 36 patients screened, 12 were excluded according to the prespecified exclusion criteria. All 24 eligible patients were counseled regarding 12 weeks of nonoperative splinting; eight declined surgery and elected nonoperative treatment, whereas 16 underwent the present procedure. The wires were buried beneath the skin, and the temporary splint was replaced with an opencast at 1 week, permitting showering and protected daily and sports activities, including activities requiring hand use. The wires were routinely removed at 8 weeks, after which active DIP motion was initiated; a removable brace was then worn only during outdoor or sports activities for 4 weeks. This approach addresses a different clinical priority from the final extension result. Although operative and nonoperative treatment may achieve comparable final outcomes, the present protocol was designed to reduce restrictions during treatment, facilitate earlier return to daily and sports activities, and potentially improve convenience, satisfaction, and quality of life.

### Interpretation

Practical problems arise during splint treatment, the most fundamental of which is compliance. Because the terminal tendon has a limited blood supply and heals through scar formation, interruption of immobilization allows it to stretch again [15]. Even brief DIP joint flexion while


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washing the hand without the splint may disrupt healing and necessitate restarting the immobilization period. Accordingly, under our institutional nonoperative treatment protocol, all patients were initially counseled to undergo continuous full-time DIP joint splinting for 12 weeks. With the present technique, internal K-wire fixation maintained the DIP position and allowed showering and protected daily and sports activities from 1 week. Routine K-wire removal at 8 weeks enabled active DIP motion 4 weeks earlier than completion of the 12-week full-time nonoperative splinting protocol, although a removable brace was still used during outdoor or sports activities until week 12. This represents earlier functional progression rather than proof of faster tendon healing. Nevertheless, earlier progression from rigid immobilization to active motion and continued participation in daily and protected sports activities are practical advantages that may lessen the effect of treatment on work, recreation, and quality of life.

A second concern is skin and hygiene-related complications. Stern and Kastrup reported a 45% complication rate among 84 splinted digits; most complications were skin-related and transient [10]. A continuously enclosed splint creates a warm, moist environment through perspiration, leading to maceration and malodor; this is also a common reason for patients to remove the splint without medical advice. Thus, hygiene and compliance problems are causally linked rather than independent. With the present technique, the use of an opencast and tissue adhesive from 1 week postoperatively allows direct wound cleansing and showering while reducing occlusion-related perspiration and maceration [12]. The absence of exposed wires and protection with an opencast may make selected sports activities more practical; however, activities involving substantial direct impact to the affected finger should be avoided. By reducing restrictions on washing, routine hand use, and protected activity, this protocol may also improve treatment convenience and indirectly support compliance.

A third concern is control of extension lag. As swelling subsides during splint treatment, the splint may loosen and the actual immobilization position of the DIP joint may gradually shift toward flexion. Over time, these subtle positional changes may contribute to residual extension lag [11]. Because some residual extension loss commonly occurs after treatment, we fixed the DIP joint in approximately 15° of hyperextension rather than neutral in an attempt to compensate for this loss. The mean residual extension lag of 1.9° at 6 months is consistent with this rationale, but the absence of a control group prevents a causal conclusion.

The degree of hyperextension must nevertheless be selected carefully. Rayan and Mullins reported that perfusion of the dorsal skin over the DIP joint decreases in proportion to the degree of hyperextension and that excessive hyperextension may cause skin necrosis [16]. We selected 15° as a compromise that we considered sufficient to compensate for extension loss after K-wire removal without substantially compromising dorsal skin perfusion. In addition, after tourniquet release, the operating orthopedic hand specialist inspected the nail bed and eponychium and confirmed intact capillary refill before completion of each procedure. No dorsal skin necrosis occurred in this study.

K-wire removal was routinely scheduled at 8 weeks based on the time required for the healing terminal tendon to acquire sufficient tensile strength [6]. It was completed at the ambulatory surgery center without hospitalization under local anesthesia in approximately 5 minutes, at a cost of approximately 120,000 Korean won. Active DIP motion was initiated after removal. Compared with our institutional protocol of 12 weeks of continuous full-time nonoperative splinting, this protocol allowed active DIP motion from 8 weeks in routine cases; a removable mallet brace was used only during outdoor or sports activities for the subsequent 4 weeks. Thus, the protocol shortened the period of rigid immobilization and facilitated earlier functional progression. These treatment-period advantages may be meaningful to patients even if final clinical outcomes are similar, although comparative studies are required to quantify their effect on satisfaction and quality of life.

### Comparison with previous studies

Multiple studies have consistently reported no significant difference in final clinical outcomes between nonoperative and operative treatment of mallet finger injuries [8,17]. A Cochrane systematic review also concluded that the evidence was insufficient to support the superiority of any particular treatment [7].

Conventional techniques that leave K-wires exposed outside the skin have been associated with pin-site infection, soft-tissue injury, and wire migration [18,19]. We cut

the wires with a dedicated cutter and buried them beneath the skin [12]. Nevertheless, superficial pin-site infection occurred in two patients and resolved with oral antibiotics and local wound care. One separate patient developed wire loosening with painful subcutaneous prominence, which was managed with the spare aluminum splint and close follow-up. To address this risk proactively, a spare aluminum splint was fabricated in the operating room for each patient, and patients were instructed to apply it and seek immediate assessment if loosening was suspected. These findings indicate that wire-related complications remain possible even with subcutaneous burial, although all events in this series were managed without additional surgery.

For chronic or neglected tendinous mallet finger, reported surgical options include tenodermodesis [20], direct terminal tendon repair, spiral oblique retinacular ligament reconstruction, and, in severe cases, DIP joint arthrodesis [2,5]. These procedures require soft-tissue dissection and reconstruction and are therefore relatively invasive and associated with longer recovery. The present technique is a simple percutaneous procedure that does not require joint exposure or extensive soft-tissue dissection. Moreover, failure does not preclude subsequent use of the aforementioned procedures, making it a potentially useful initial surgical option.

### Limitations

The disadvantages of this technique are clear. First, subcutaneous wire burial requires a second procedure for removal, although in our practice this was completed without hospitalization at an ambulatory surgery center under local anesthesia in approximately 5 minutes and cost approximately 120,000 Korean won. Second, wire-related complications remain possible. Two patients developed superficial pin-site infections, and one separate patient developed wire loosening with painful subcutaneous prominence; all events were managed with oral antibiotics, local wound care, close follow-up, or aluminum-splint application, without additional surgery. Third, wires inserted from the fingertip could theoretically injure the nail apparatus. However, the insertion trajectory did not pass through the nail bed or nail matrix, and no transient or permanent nail abnormality was observed. Fourth, there is a theoretical risk of cartilage injury from wires crossing the articular surface.

This study has several limitations. First, it was a retrospective study with a small, self-selected surgical cohort. Of 36 patients screened, 12 were excluded according to the prespecified criteria. Although nonoperative treatment was recommended to all 24 eligible patients, eight declined surgery and elected nonoperative treatment, introducing selection bias. Outside the study period, we also encountered a number of patients with tendinous mallet finger who declined surgical treatment after counseling, further emphasizing that the decision to undergo surgery is strongly influenced by individual preferences regarding treatment burden and activity restrictions. Second, there was no direct comparison with the patients treated nonoperatively; therefore, the magnitude of any advantage in treatment-period convenience, satisfaction, quality of life, or time to return cannot be quantified. Third, all angular measurements were performed by the operating surgeon without an independent assessor, creating a risk of observer bias. Fourth, the 6-month follow-up was relatively short and did not permit assessment of long-term changes in extension lag or DIP degeneration. Fifth, subsequent sports participation was confirmed only by direct patient questioning; the exact timing and intensity of return to each sport were not systematically recorded or independently verified. Finally, no validated instrument was used to quantify satisfaction regarding hygiene and activity restrictions.

### Generalizability

Splinting remains the primary treatment for acute closed mallet finger injuries [5,21], and the present technique should not be recommended universally. Rather, it should be considered selectively for patients who are unable or unwilling to accept the burdens inherent in prolonged splint treatment. In such patients, treatment-period convenience and the ability to continue usual activities may be clinically meaningful even when the expected final range of motion is not superior.

### Suggestions

Future studies should directly compare final extension lag at different hyperextension angles.

Prospective comparative studies using validated patient-reported outcome measures are required to confirm the treatment-period benefits of this protocol.


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### Conclusions

Although final clinical outcomes after operative and nonoperative treatment of acute tendinous mallet finger may not differ substantially, the burden experienced during treatment differs between the two approaches. Under our institutional nonoperative treatment protocol, continuous full-time DIP joint splinting is maintained for 12 weeks, which can cause hygiene problems, restrict routine hand use and sports participation, and delay functional return. In contrast, percutaneous K-wire fixation in approximately 15° of hyperextension with subcutaneous wire burial and opencast application permitted showering and protected daily and sports activities from 1 week. Routine wire removal at 8 weeks allowed active DIP joint motion, with a removable brace required only during outdoor or sports activities for the subsequent 4 weeks. Therefore, this technique may reduce the inconvenience associated with prolonged full-time splinting; however, whether it leads to earlier return to activity or improves satisfaction and quality of life remains to be established. The two superficial pin-site infections and the single separate case of wire loosening were managed without additional surgery. Although this technique should not replace standard nonoperative treatment in all patients, it may be a useful alternative for selected patients who prioritize hygiene, continued hand use, sports participation, and fewer treatment-related restrictions.

## Article Information

### Author contributions

Conceptualization: SYJ. Data curation: HJK, JWK. Methodology: SYJ. Formal analysis: MKC. Validation: SYJ. Investigation: HJK, JWK. Supervision: SYJ. Writing–original draft: HJK, JWK. Writing–review & editing: HJK, JWK, MKC, SYJ. All authors read and approved the final manuscript.

### Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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None.

### Data availability

All data supporting the findings of this study are available in the manuscript and Table 1.

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### Supplementary materials

None.

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# Proximal screw number and neck-shaft angle after locking plate fixation of proximal humerus fractures at a single center in Korea: a retrospective cohort study

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**Background:** The neck-shaft angle (NSA) may decrease between the immediate postoperative assessment and radiographic union after locking plate fixation of proximal humerus fractures. However, the relationship between the number of proximal humeral head screws and postoperative NSA remains unclear. This study compared postoperative NSA and the change in NSA (ΔNSA) among groups defined by the number of proximal screws.

**Methods:** This retrospective cohort study included consecutive patients who underwent locking plate fixation of a proximal humerus fracture between August 2025 and June 2026. Patients were classified into three groups according to the number of proximal screws: ≤7, 8, or 9. NSA was measured preoperatively, immediately postoperatively, and at radiographic union, hereafter referred to as the final assessment. Final NSA, ΔNSA, the proportions of patients with varus malalignment (final NSA <120°) and angular loss of reduction (ΔNSA ≤−10°), and complication rates were compared among groups. Trends across increasing screw numbers were also assessed.

**Results:** Nineteen patients were evaluated: nine in the ≤7-screw group, four in the 8-screw group, and six in the 9-screw group. Immediate postoperative NSA was 140.1°±5.7°, 136.2°±11.8°, and 134.0°±6.2° in the three groups, respectively; final NSA was 131.6°±9.2°, 129.5°±16.1°, and 130.2°±8.3°; and ΔNSA was −8.6°±8.8°, −6.8°±4.6°, and −3.8°±5.2°. None of these outcomes differed significantly among groups (all P>0.05). Varus malalignment occurred in 22.2%, 25.0%, and 16.7% of patients, respectively (P>0.999). Angular loss of reduction occurred in 44.4%, 25.0%, and 0%, respectively; neither the overall group difference (P=0.163) nor the trend across groups (P=0.056) reached statistical significance. Complication rates also did not differ significantly among groups.

**Conclusions:** In this small retrospective cohort, the number of proximal screws was not significantly associated with final NSA or ΔNSA. Although the proportion of patients with angular loss of reduction decreased numerically as the screw number increased, this trend was not statistically significant and should be regarded as exploratory.

**Level of evidence:** III.

**Keywords:** Humeral fractures; Bone plates; Bone screws; Internal fracture fixation; Treatment outcome

**Original Article**

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## Introduction

### Background/rationale

Proximal humerus fracture (PHF) is the third most common osteoporotic fracture following proximal femur and distal radius fractures [1,2]. These fractures can be treated either conservatively or operatively, and operative options include locking plate fixation, intramedullary nailing, and shoulder arthroplasty [3-7]. Locking plates for PHFs have been widely used and are associated with a high union rate [8,9]. However, even after locking plate fixation, a decrease in the neck-shaft angle (NSA) has been reported between the immediate postoperative period and the time of bony union [10]. Several factors—including the number and position of calcar screws, the quality of initial reduction, medial hinge/calcar support, and patient bone quality—have been reported to be associated with a decrease in NSA or varus collapse after locking plate fixation [9,11-13]. A previous biomechanical study investigated the optimal number of screws inserted into the humeral head, but the evidence did not simply indicate that more screws are better; similarly, in previous clinical studies, the number of screws in the humeral head has not been significantly associated with loss of reduction or varus collapse [14,15]. Nevertheless, studies specifically focusing on the relationship between the number of screws in the humeral head and postoperative NSA or the change in NSA after locking plate fixation remain limited.

### Objectives

The primary aim was to compare final NSA and the change in NSA (ΔNSA) among proximal screw-number groups. The secondary aim was to compare complication rates according to the number of proximal screws. We hypothesized that the final NSA would be higher and that the decrease in NSA would be smaller in patients with a greater number of proximal screws.

## Methods

### Ethics statement

We conducted this study in compliance with the principles of the Declaration of Helsinki. The study protocol was reviewed and approved by the Institutional Review Board (IRB) of Gil Medical Center (No. GAIRB 2026-284). Informed consent was waived by the IRB due to the retrospective nature of the study.

### Study design

This single-center, retrospective cohort study included consecutive patients aged 18 years or older who underwent open reduction and internal fixation with a locking plate for a PHF involving the surgical neck by two upper-extremity fellowship-trained orthopedic surgeons (SPS and DUJ).

### Setting

This study was conducted at Gil Medical Center, Incheon, Korea. Operations were performed from August 2025 through June 2026, and follow-up and data collection continued through August 2026.

### Participants

Fractures were classified according to the Neer classification system [16]. Patients were included if they had plain radiographs obtained preoperatively, immediately postoperatively, and at the time of radiographic union, defined as bridging callus visible across at least three cortices on two orthogonal radiographic views. Patients were excluded if they had (1) isolated greater tuberosity (GT) or lesser tuberosity fracture, (2) a history of previous surgery on the ipsilateral shoulder, (3) a pathologic or open fracture, (4) failure to achieve radiographic union, including early fixation failure requiring revision surgery or death prior to union assessment, or (5) inadequate image quality precluding precise radiological assessment. All fixations were performed using one of two locking plate systems: the PHILOS (proximal humeral internal locking system, DePuy Synthes) or the ARIX Humerus System (Jeil Medical Corp.). Both systems are anatomically pre-contoured, angular-stable locking plates with combination-type proximal screw holes accommodating up to nine locking screws in the humeral head. The choice of implant was based on surgeon preference and institutional availability.

### Variables

The exposure variable was the number of proximal humeral head screws, categorized as ≤7, 8, or 9. The coprimary outcomes were final NSA and ΔNSA. Secondary outcomes were varus malalignment, angular loss of reduction, screw-related complications, and avascular necrosis. Im-


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mediate postoperative NSA served as the postoperative reference measurement for calculating ΔNSA.

Patients were originally classified according to the exact number of proximal (humeral head) screws (6, 7, 8, or 9). Because only two patients received 6 screws, these patients were combined with the 7-screw group into a single ≤7-screw category, resulting in three groups for analysis (≤7, 8, and 9 screws). ΔNSA was defined as the difference in NSA between the final and immediate postoperative assessments (final NSA – immediate postoperative NSA). A final NSA <120° was defined as varus malalignment, and a ΔNSA ≤–10° was defined as angular loss of reduction. Postoperative NSA, ΔNSA, the proportions of varus malalignment, angular loss of reduction, and complication rates were compared among the three groups, and trends according to increasing screw number were analyzed.

### Data sources/measurement

Patient demographics and radiologic images were retrieved from electronic medical records for assessment. The NSA was measured using a previously described technique by Agel et al. [17] on anteroposterior shoulder radiographs at three time points: preoperatively, immediately postoperatively, and at the time of radiographic union (hereafter referred to as the final assessment) (Fig. 1). All NSA measurements used in the primary analysis, including the immediate postoperative NSA, were performed by a single observer (SPS, an upper-extremity fellowship-trained surgeon). To assess measurement reliability, preoperative and final NSA were additionally measured by a second observer (YCK, a senior orthopedic resident), and observer 1 (SPS) repeated the preoperative and final NSA measurements after a 2-week interval, blinded to the initial measurements. Intraobserver reliability was calculated from observer 1's two measurements, and interobserver reliability was calculated between observer 1's initial measurement and observer 2's measurement, using a two-way random effects, absolute-agreement, single-measures intraclass correlation coefficient (ICC[2,1]).

### Bias

Confounding by indication arose because surgeons selected screw number according to fracture severity. Consecutive enrollment and predefined criteria reduced selection bias, but excluding failures before union may cause survivor bias.



**Fig. 1.** Measurement of the neck-shaft angle on an anteroposterior shoulder radiograph using the method described by Agel et al. [17]. The asterisk denotes the measured angle.

### Study size

No formal sample size calculation was performed. All consecutive eligible patients treated during the study period were included; therefore, the study size was determined by available cases meeting the eligibility and radiographic follow-up criteria.

### Statistical methods

Continuous variables are presented as mean±standard deviation and categorical variables as number (%). Intra- and interobserver reliability of NSA measurements was assessed using ICCs [18]. Continuous variables, including baseline demographic and fracture characteristics and NSA at each time point, were compared among the three screw-number groups using the Kruskal-Wallis test; when a significant difference was found, post-hoc pairwise comparisons were performed using the Mann-Whitney U test with a Bonferroni-corrected significance threshold (P<0.0167). Independently of statistical significance, effect sizes (epsilon-squared for omnibus comparisons;

Cohen's d and 95% confidence intervals (CIs) for the mean difference between the ≤7- and 9-screw groups) were additionally calculated for the primary continuous outcomes to aid interpretation of the magnitude of observed differences. Because the three groups were ordinal, the Jonckheere-Terpstra test was additionally used to assess a monotonic trend across the ordered groups for continuous outcome and surgical variables (NSA at each time point, calcar screw number, and time to union). Categorical variables, including baseline demographic and fracture characteristics, the proportions of patients with varus malalignment and angular loss of reduction, and complication rates detected through radiographic union, were compared among the three groups using the Fisher-Freeman-Halton exact test; when a significant difference was found, post-hoc pairwise comparisons were performed using Fisher exact test with a Bonferroni-corrected significance threshold (P<0.0167). The Cochran-Armitage trend test was used to assess a trend across the ordered groups for the binary outcome variables (varus malalignment, angular loss of reduction, and complication rates detected through radiographic union). The change in NSA from the immediate postoperative assessment to the final assessment within each group was assessed using the Wilcoxon signed-rank test. Because of the small sample size and limited number of outcome events, multivariable adjustment was not performed; all between-group comparisons were unadjusted. All statistical analyses were performed using IBM SPSS for macOS, ver. 31 (IBM Corp.), with P<0.05 considered statistically significant.

## Results

### Participants

Of the 24 patients initially identified, five were excluded: two had isolated GT fractures, two underwent revision surgery due to early fixation failure prior to achieving radiographic union, and one died before union could be radiographically assessed. Therefore, a total of 19 patients were enrolled. According to proximal screw numbers, nine, four, and six patients were classified into ≤7-, 8-, and 9-screw groups, respectively; the ≤7-screw group comprised two patients with six screws and seven patients with seven screws. All 19 patients achieved radiographic union and the mean time to radiographic union was 4.2±1.5 months (range, 2–6 months) overall and did not differ significantly among the ≤7-, 8-, and 9-screw groups (4.3±1.7, 4.0±1.4, and 4.0±1.6 months, respectively; P=0.905; trend P=0.647). There were no significant differences among the three screw-number groups in demographics or fracture characteristics, except for alcohol use and medial metaphyseal comminution. Alcohol use differed significantly among groups (P=0.047), being most frequent in the ≤7-screw group, although no individual pairwise comparison remained significant after Bonferroni correction. Medial metaphyseal comminution was significantly more frequent in the 8-screw group compared with the ≤7-screw group (post-hoc P=0.007). Regarding surgical characteristics, the distribution of plate type differed significantly among groups (P=0.047), with a higher proportion of the ARIX system in the 9-screw group; as with alcohol use, no individual pairwise comparison remained significant after Bonferroni correction. The number of calcar screws differed significantly (P=0.028; trend P=0.040), with all patients in the 9-screw group receiving two calcar screws; however, no individual pairwise comparison reached significance after Bonferroni correction. Detailed baseline characteristics are summarized in Table 1.

### Main results

The ICCs for intra- and interobserver reliability of NSA measurements were 0.947 (95% CI, 0.898–0.971) and 0.924 (95% CI, 0.859–0.960), respectively. The mean immediate postoperative NSA was 140.1°±5.7°, 136.2°±11.8°, and 134.0°±6.2° in the ≤7-, 8-, and 9-screw groups, respectively, and did not differ significantly among groups, although a decreasing pattern was observed with increasing screw number (P=0.203; trend P=0.073; $\varepsilon^2$=0.177) (Fig. 2). The mean difference between the ≤7- and 9-screw groups was 6.11° (95% CI, –0.62° to 12.85°; Cohen's d=1.03). The final NSA (131.6°±9.2°, 129.5°±16.1°, and 130.2°±8.3°, respectively) did not differ significantly among groups (P=0.812; trend P=0.647; $\varepsilon^2$=0.023; mean difference between ≤7- and 9-screw groups, 1.39°; 95% CI, –8.68° to 11.46°; Cohen's d=0.16) (Fig. 2), nor did ΔNSA (–8.6°±8.8°, –6.8°±4.6°, and –3.8°±5.2°, respectively; P=0.731; trend P=0.517; $\varepsilon^2$=0.035; mean difference, –4.72°; 95% CI, –13.42° to 3.98°; Cohen's d=0.62) (Fig. 3). Within each group, NSA decreased significantly from the immediate postoperative to the final assessment in the ≤7-screw group (P=0.012), while it did not


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**Table 1.** Patient demographics and fracture characteristics according to the number of proximal screws

| Variable | ≤7 (n=9) | 8 (n=4) | 9 (n=6) | P-value |
|---|---|---|---|---|
| Demographic characteristics | | | | |
| Age (yr) | 65.2±14.1 | 66.2±25.0 | 75.8±18.1 | 0.267 |
| Female sex | 5 (55.6) | 1 (25.0) | 4 (66.7) | 0.604 |
| Hypertension | 6 (66.7) | 2 (50.0) | 5 (83.3) | 0.695 |
| Diabetes | 1 (11.1) | 0 (0) | 1 (16.7) | >0.999 |
| Previous fracture | 1 (11.1) | 2 (50.0) | 3 (50.0) | 0.234 |
| Smoking | 2 (22.2) | 2 (50.0) | 0 (0) | 0.198 |
| Alcohol use | 5 (55.6) | 1 (25.0) | 0 (0) | 0.047 |
| Albumin (g/dL) | 4.1±0.6 | 3.8±0.8 | 4.0±0.4 | 0.429 |
| Creatinine (mg/dL) | 1.6±2.5 | 0.8±0.2 | 0.8±0.3 | 0.517 |
| Fracture characteristics | | | | |
| Preoperative varus angulation[a] | 4 (44.4) | 4 (100) | 2 (33.3) | 0.121 |
| Preoperative neck-shaft angle (°) | 142.3±28.6 | 113.0±20.3 | 139.0±23.4 | 0.261 |
| Two-part fracture | 8 (88.9) | 2 (50.0) | 5 (83.3) | 0.282 |
| Medial metaphyseal comminution | 1 (11.1) | 4 (100) | 2 (33.3) | 0.008 |
| Surgical characteristics | | | | |
| Plate (ARIX:PHILOS) | 4:5 | 3:1 | 6:0 | 0.047 |
| Calcar screw number | 1.2±0.7 | 1.3±0.5 | 2.0±0.0 | 0.028 |

Values are presented as mean±standard deviation or number (%).
[a]Preoperative neck-shaft angle <135°.

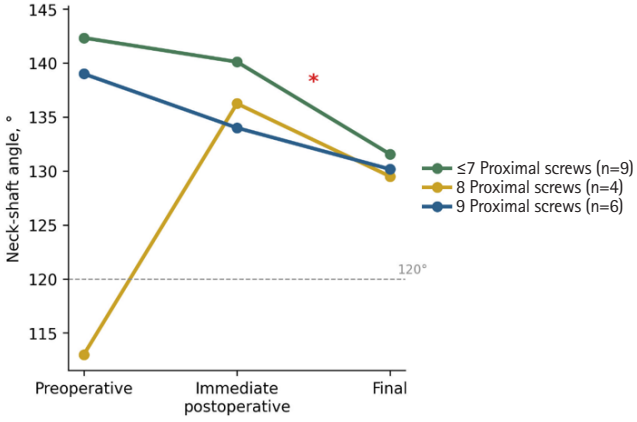



**Fig. 2.** Mean neck-shaft angle at the preoperative, immediate postoperative, and final assessments, stratified by the number of proximal screws. The final assessment was performed at radiographic union. The asterisk indicates a statistically significant within-group change from the immediate postoperative to the final assessment. *P<0.05.

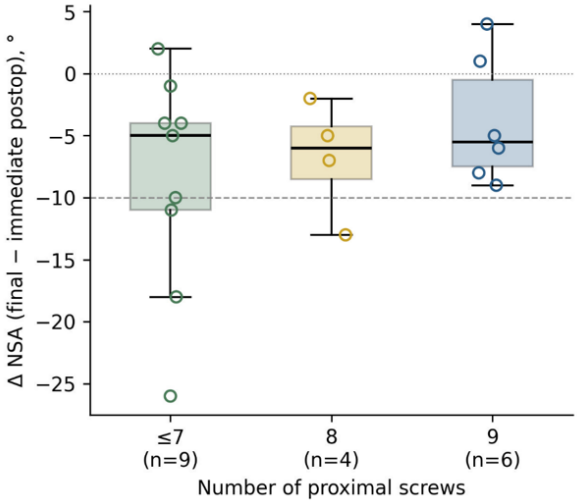



**Fig. 3.** Change in neck-shaft angle (NSA) from the immediate postoperative assessment to the final assessment, stratified by the number of proximal screws. ΔNSA was calculated as final NSA minus immediate postoperative NSA.

reach statistical significance in the 8- and 9-screw groups (P=0.125 and P=0.156, respectively) (Fig. 2).

Varus malalignment occurred in two of nine (22.2%), one of four (25.0%), and one of six (16.7%) patients, respectively, with no significant difference (P>0.999) or trend (P=0.813) across groups (Fig. 4). Angular loss of reduction occurred in four of nine patients (44.4%) in the ≤7-screw group, one of four (25.0%) in the 8-screw group, and zero of six (0%) in the 9-screw group (Fig. 4). Neither the overall difference among groups (P=0.163) nor the Cochran-Armitage trend test (P=0.056) reached statistical significance.

Screw-related complications occurred in three of nine

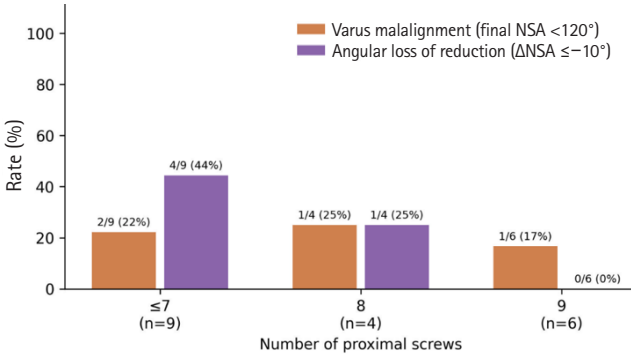



**Fig. 4.** Proportions of patients with varus malalignment and angular loss of reduction, stratified by the number of proximal screws. Varus malalignment was defined as a final neck-shaft angle <120°, and angular loss of reduction was defined as ΔNSA ≤−10°. NSA, neck-shaft angle.

(33.3%), one of four (25.0%), and one of six (16.7%) patients in the ≤7-, 8-, and 9-screw groups, respectively, with no significant difference (P=0.814) or trend (P=0.471) across groups. All five screw-related complications involved partial screw pull-out from the humeral head; none required revision surgery. Avascular necrosis occurred in zero, one (25.0%), and zero patients, respectively (P=0.211; trend P=0.853); the single case of avascular necrosis was identified at 6 months postoperatively.

## Discussion

### Key results

This study compared the postoperative NSA and ΔNSA according to the number of proximal screws and showed that the number of proximal screws was not significantly associated with the final NSA, ΔNSA, varus malalignment, angular loss of reduction, or complication rates. In addition, NSA decreased from the immediate postoperative to the final assessment in all screw groups, while statistical significance was achieved only in the ≤7-screw group.

### Interpretation

An important consideration in interpreting these findings is that the number of screws was determined by the operating surgeon's judgment rather than by a standardized protocol, and fracture severity was not balanced among the groups. In particular, medial metaphyseal comminution was present in all four patients in the 8-screw group compared with only one of nine patients in the ≤7-screw group, and the 8-screw group also had a numerically lower preoperative NSA, although the difference was not statistically significant. The immediate postoperative NSA showed a decreasing pattern with increasing screw number, although the trend was not statistically significant; the ≤7-screw group had the highest value. These observations suggest that surgeons may have used a greater number of screws in more severely comminuted or unstable fractures, in which anatomic reduction itself was more difficult to achieve, making it difficult to separate any independent effect of screw number from the influence of fracture severity. A related observation was that the number of calcar screws also differed significantly among the three groups, with all patients in the 9-screw group receiving the maximum of two calcar screws; however, calcar screw number was similar between the ≤7- and 8-screw groups despite their differing fracture severity, indicating that calcar screw fixation alone does not fully account for the differences observed across groups.

Despite this less favorable preoperative status in the 8-screw group, the rate of angular loss of reduction was numerically lower with increasing screw number, and the Cochran-Armitage trend test did not reach statistical significance—an exploratory secondary observation. This pattern suggests that angular loss of reduction may have been comparatively low in the 8-screw group despite a more severe preoperative fracture status and a calcar screw distribution similar to that of the ≤7-screw group, although this cannot be distinguished from chance given the small sample size and the fact that this trend involved only five events among 19 patients. Given the limited statistical power and this confounding by fracture severity, the observation should be regarded as hypothesis-generating rather than evidence of an association between screw number and reduction maintenance, and confirmation in a larger, multicenter cohort with more balanced fracture characteristics is required.

### Comparison with previous studies

Varus malalignment after locking plate fixation of PHFs has been consistently associated with poor clinical outcomes [19-21]. In a large cohort of 685 patients with a minimum 2-year follow-up, Fleischhacker et al. [19] reported progressively lower Constant scores with increasing degrees


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of varus malposition. Dheenadhayalan et al. [20] reported that an NSA <120° was associated with poorer functional outcomes and more limited shoulder abduction. Similarly, Kantharaju et al. [21] reported that patients with NSA <126° had a significantly worse Constant score than those with a normal NSA. Given these clinical consequences, preventing varus malalignment—or, more fundamentally, preventing angular loss of reduction before it progresses to malalignment—is of considerable clinical importance.

Regarding the optimal number of proximal screws, a biomechanical study by Kim et al. [14] compared four-, six-, seven-, and nine-screw constructs and found that the seven-screw group had the numerically highest load to failure and stiffness, and the lowest structural failure rate. Post-hoc pairwise comparisons showed no significant difference between the seven- and nine-screw groups in load to failure or structural failure rate, suggesting a plateau effect beyond a certain screw number rather than a continuously increasing benefit. Consistent with this biomechanical plateau, previous clinical studies have not identified proximal screw number as a significant risk factor for varus malalignment or loss of fixation; Maddah et al. [15], for example, reported no significant difference in the mean number of screws between patients with and without loss of fixation. The present findings are consistent with this body of literature: within the range of screw numbers evaluated in this cohort, no significant association was observed between screw number and postoperative NSA, final NSA, ΔNSA, varus malalignment, angular loss of reduction, or complication rates.

A decrease in NSA between the immediate postoperative period and bony union has been consistently reported after locking plate fixation of PHFs, with most of this decrease occurring within the first 1 to 3 months postoperatively rather than progressing steadily thereafter [10,22]. Pawaskar et al. [10] serially measured NSA in elderly patients treated with locking plates and found that the NSA decreased from 133.6° immediately postoperatively to 129.8° at 3 months and 128.4° at final follow-up, with the majority of the loss occurring within the first 3 months. In the present study, a similar decreasing pattern was observed across all three screw-number groups, consistent with these previous reports, and a significant within-group decrease was observed only in the ≤7-screw group. However, this within-group finding does not permit a direct comparison between groups: the overall between-group comparison of ΔNSA was not significant, and the 8-screw group had limited statistical power to detect a significant within-group change regardless of its true magnitude.

### Limitations

This study has several limitations. First, the small sample size in this study limited the statistical power to detect differences among groups and increased the risk of a type II error; larger, multicenter studies are needed to confirm these findings. Second, although our institution uses a standardized radiographic technique for the shoulder anteroposterior view, the technique and arm position could not be fully controlled because of the retrospective design. Third, this study evaluated radiographic outcomes only, without correlating these findings with clinical or functional outcomes. Fourth, although there were no statistically significant differences in most baseline demographics and fracture characteristics among the three groups, the number of screws used was determined by the operating surgeon's judgment, rather than by randomization. However, randomizing this decision would not have been feasible or ethical, as it could compromise fixation quality and patient safety. Fifth, ΔNSA is partly dependent on the immediate postoperative starting value and may be affected by mathematical coupling and regression to the mean; a larger ΔNSA should therefore not be interpreted as an independent effect of screw number, and the similarity of final NSA across groups should be considered at least as informative. Sixth, patients who did not achieve radiographic union were not eligible for inclusion, as final NSA could not be measured without a union radiograph. This may have introduced selection bias by excluding patients at the greatest risk of reduction loss. Seventh, the surveillance period for complications, including avascular necrosis, was limited to the time of radiographic union, which may be insufficient to capture the full incidence of late-onset complications. Finally, proximal screw number was closely associated with implant type and calcar screw number, particularly because all patients in the 9-screw group received an ARIX plate and two calcar screws. Therefore, the independent effect of total screw number could not be isolated.

Despite these limitations, this study is meaningful in that it evaluated the relationship between the number of prox-

imal screws and both the final NSA and the change in NSA with serial follow-up.

### Generalizability
Findings may apply to similar adults treated with locking plates at specialized centers, but the single-center, small, selected union cohort limits broader generalizability.

### Suggestions for further studies
Larger multicenter prospective cohorts should assess screw number while controlling for fracture severity, medial support, screw configuration, bone quality, and initial reduction.

### Implication
Given the exploratory findings, proximal screw number alone should not guide fixation; surgeons should prioritize reduction quality, medial support, bone quality, and screw configuration.

### Conclusions
In this selected cohort of patients who achieved radiographic union without early revision, no statistically significant unadjusted differences in final NSA or ΔNSA were detected among screw-number groups. Although the rate of angular loss of reduction decreased numerically with increasing screw number, this finding did not reach statistical significance and should be considered exploratory. Larger studies controlling for fracture severity, medial support, and screw configuration are required to determine whether proximal screw number independently affects maintenance of reduction.

## Article Information

### Author contributions
Conceptualization: DUJ, KHJ, SPS. Data curation: DUJ, SHK, YCK. Methodology: DUJ, KHJ, SPS. Formal analysis: YCK, SPS. Investigation: DUJ, YCK, SPS. Validation: YCK. Supervision: KHJ, SPS. Project administration: SPS. Visualization: SHK. Writing–original draft: DUJ. Writing–review & editing: SHK, YCK, KHJ, SPS. All authors read and approved the final manuscript.

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The datasets generated and analyzed during the current study are not publicly available due to patient confidentiality constraints and the terms of the approved ethics protocol. Deidentified data are available from the corresponding author upon reasonable request and subject to institutional data sharing agreements.

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### Supplementary materials
None.

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# Progressive forearm instability after anatomical union of a radial head fracture: a case report of a challenging Essex–Lopresti injury

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Essex-Lopresti injuries remain challenging because anatomical restoration of bony structures does not always re-establish functional forearm stability. We report the case of a 51-year-old male patient who sustained an elbow dislocation, comminuted radial head and neck fracture, and distal radioulnar joint (DRUJ) dissociation after falling from a bicycle. He underwent open reduction and internal fixation of the radial head, interosseous membrane augmentation using a suture-button construct, and temporary DRUJ pinning. Immediate postoperative radiographs showed apparent restoration of radial length, and radiographic union of the radial head was achieved. However, ulnar-sided wrist pain initially improved but progressively recurred by 6 months, with increasing ulnar-positive variance and DRUJ widening. Elbow motion was preserved, but forearm rotation was limited, and computed tomography demonstrated heterotopic ossification around the radial head. Ulnar shortening osteotomy and radial head arthrolysis were performed as a second procedure, after which mechanical instability developed, with irreducible anterior dislocation of the radial head. A third operation, consisting of annular ligament reconstruction using a palmaris longus autograft, restored proximal radioulnar joint stability, although substantial limitation of forearm rotation persisted. This case highlights that even radiographic union and multistructural initial management may fail to restore balanced forearm mechanics in Essex-Lopresti injury.

**Level of evidence:** V.

**Keywords:** Radius fractures; Forearm injuries; Joint instability; Wrist injuries; Case reports

Case Report

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## Introduction

Essex-Lopresti injury is an uncommon but potentially devastating form of longitudinal forearm instability that is frequently underestimated when a radial head fracture is treated as an isolated injury [1,2]. Delayed recognition or incomplete restoration of the injured stabilizers may lead to proximal migration of the radius, distal radioulnar joint (DRUJ) dysfunction, ulnocarpal impaction, pain, and loss of forearm rotation [1-3].

Management of Essex-Lopresti injury therefore requires more than fracture fixation alone. The forearm should be regarded as a single biomechanical unit consisting of the proximal radioulnar joint, the interosseous membrane, and the DRUJ [2,4,5]. Classic biomechanical studies have shown that the radial head is the primary osseous restraint to proximal radial migration, whereas the interosseous membrane, par-

ticularly the central band (CB), and the distal radioulnar soft tissues are essential stabilizers for longitudinal load transfer and forearm balance [4,5]. Nevertheless, optimal management remains controversial, especially in cases that progress despite apparently satisfactory restoration of bony anatomy, and no universally accepted treatment algorithm exists for chronic lesions [3,6]. We present a case of progressive forearm instability after anatomical union of a radial head fracture to highlight that restoration of radial length and fracture union do not necessarily re-establish balanced forearm mechanics in Essex-Lopresti injury.

## Case report

### Ethics statement

Written informed consent for publication of the clinical details and accompanying images was obtained from the patient.

### Patient information

A 51-year-old male patient sustained an injury to his left forearm after falling from a bicycle. At initial presentation, he had diffuse tenderness along the forearm, wrist deformity, and tenderness over the DRUJ. Radiographs demonstrated an elbow dislocation, a comminuted radial head and neck fracture, and DRUJ dissociation; consequently, an Essex-Lopresti injury was diagnosed (Fig. 1). He had no relevant past medical or surgical history. Initial surgical treatment consisted of plate fixation of the radial head. Because a metaphyseal defect remained after reduction, autologous iliac bone graft was added. Arthroscopy demonstrated complete triangular fibrocartilage complex (TFCC) disruption involving both the foveal and capsular attachments, and arthroscopic transosseous repair was performed. No degenerative disc tear or ulnocarpal chondral lesion was identified arthroscopically. Interosseous membrane augmentation using a TightRope (Arthrex) construct was then performed according to a previously described technique, with the radial and ulnar tunnel entry and exit points placed along the expected CB trajectory and the forearm held in slight supination during tensioning, followed by temporary DRUJ pinning with a single 1.2-mm K-wire (Fig. 2) [7].

### Clinical findings and timeline

The rehabilitation protocol and a concise timeline of the clinical course are provided in Table 1. Radiographic union of the radial head was achieved after the index procedure, and restoration of radial length was confirmed. However, 6 months after surgery, the patient returned with recurrent

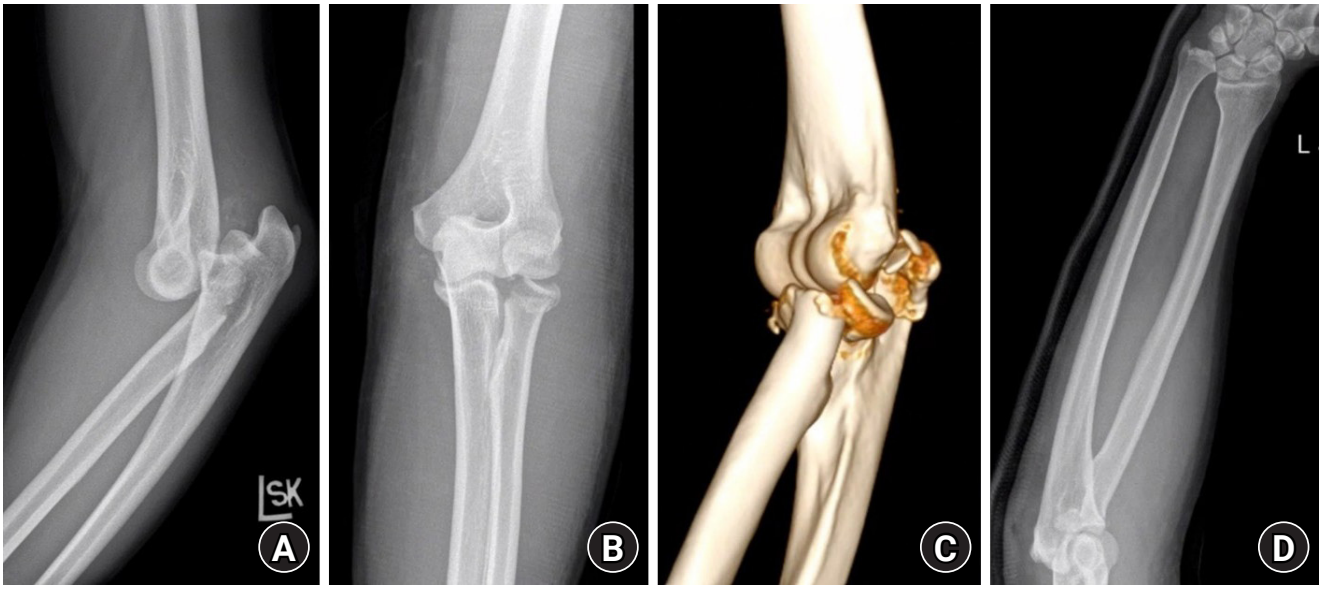



**Fig. 1.** Initial radiographs confirming Essex-Lopresti injury. (A) Lateral and (B) anteroposterior radiographs of the elbow showing elbow dislocation with a comminuted radial head and neck fracture. (C) Three-dimensional computed tomography reconstruction demonstrating the radial head and neck fracture. (D) Forearm radiograph showing distal radioulnar joint dissociation.




**Fig. 2.** Postoperative radiographs showing restoration of radial length after the index operation. (A, B) Anteroposterior and lateral radiographs of the elbow showing radial head fixation. (C, D) Wrist radiographs showing temporary distal radioulnar joint pinning and apparent restoration of radial length after interosseous membrane suture-button augmentation.

**Table 1.** Timeline of the clinical course

| Time | Clinical course |
|---|---|
| Initial injury | Bicycle fall; Essex-Lopresti injury diagnosed |
| Index surgery (1 day after injury) | Radial head open reduction and internal fixation with autologous iliac bone graft; arthroscopic transosseous repair of the triangular fibrocartilage complex; central band TightRope augmentation with radioulnar pinning using 1.2-mm K-wire |
| Rehabilitation (after index surgery) | • 3 Weeks: long arm cast maintained<br>• 6 Weeks: Munster cast removed. Velcro splint was applied, and wrist/elbow flexion-extension started<br>• 7 Weeks: DRUJ pin breakage noted<br>• 8 Weeks: pin removal; active forearm rotational ROM started |
| 6 Months after index surgery | Ulnar-sided wrist pain with secondary ulnar impaction syndrome; limited forearm rotation |
| Second surgery | Proximal arthrolysis; diaphyseal ulnar shortening osteotomy; removal of the TightRope implant |
| 3 Weeks after second surgery | New clunking sensation around the elbow; irreducible anterior radial head dislocation confirmed at follow-up |
| Third surgery | Annular ligament reconstruction using a palmaris longus autograft |
| 1 Year after third surgery | Mild residual pain; maintained radial head reduction; improved ulnar-sided wrist pain; no recurrent clunking or subjective instability |

DRUJ, distal radioulnar joint; ROM, range of motion.

ulnar-sided wrist pain and limitation of forearm rotation. Elbow flexion and extension were full, and wrist flexion and extension were preserved. Forearm rotation was limited to 70° of supination and 25° of pronation. Tenderness was present at the distal ulnar button site and the ulnocarpal joint.

### Diagnostic assessment

Follow-up radiographs at 6 months demonstrated qualitatively increasing ulnar-positive variance and DRUJ widening compared with immediate postoperative radiographs, consistent with recurrent forearm imbalance and secondary ulnar impaction syndrome. Calibrated serial measurements of ulnar variance and proximal radial migration were not available; therefore, radiographic progression was assessed qualitatively. Computed tomography revealed heterotopic ossification around the radial head (Fig. 3). Because symptoms recurred despite osseous union and restoration of radial length, a second operation was planned.


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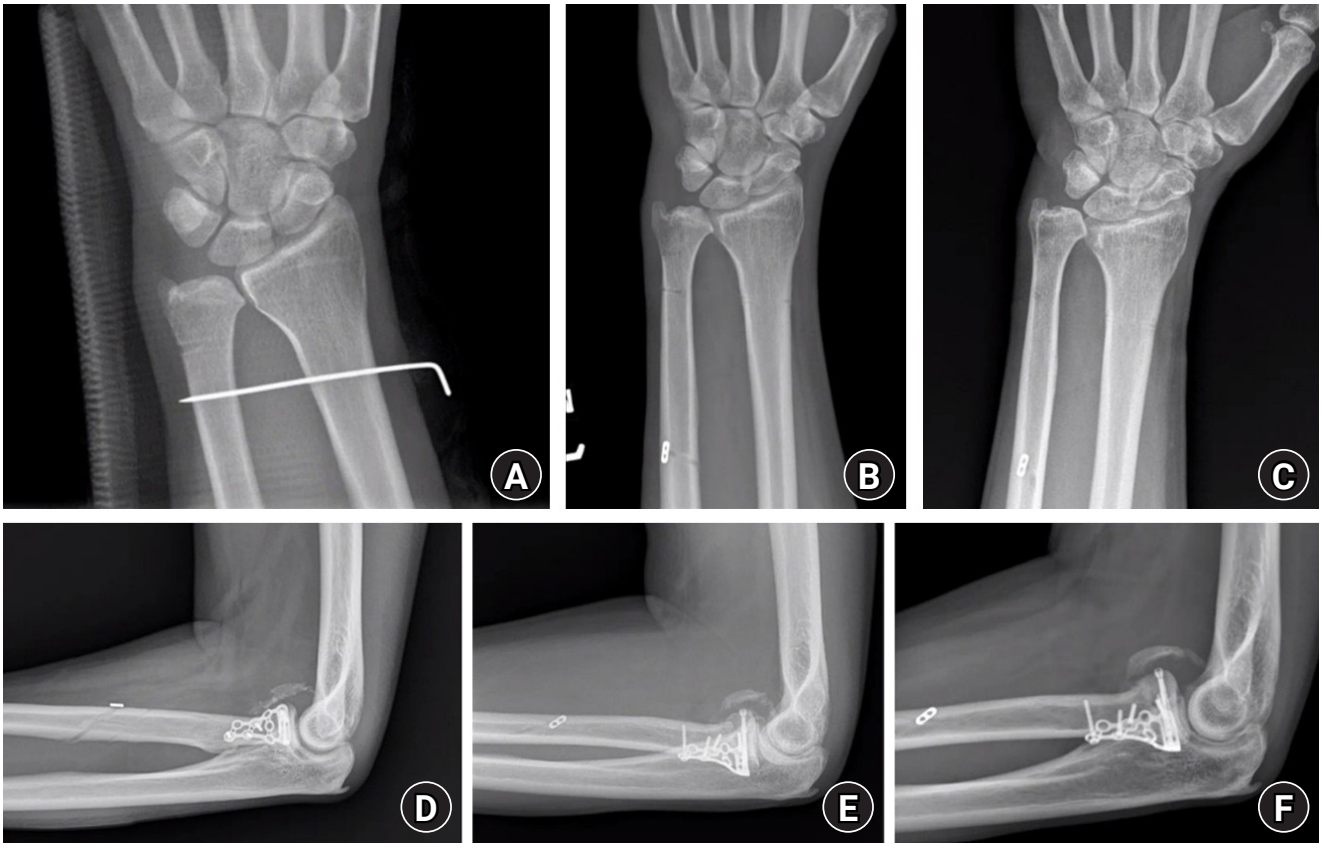



**Fig. 3.** Follow-up imaging demonstrating secondary ulnar impaction syndrome at the wrist and heterotopic ossification around the elbow. (A–C) Serial wrist radiographs showing qualitatively increased ulnar-positive variance and distal radioulnar joint widening. (D–F) Elbow radiographs showing union and heterotopic ossification around the radial head.

### Therapeutic intervention

A second operation was performed to address persistent wrist pain and limited forearm rotation. The procedure consisted of proximal arthrolysis around the radial head, diaphyseal ulnar shortening osteotomy (USO) at the midshaft level, and removal of the TightRope device because of tenderness at the distal ulnar button site and suspected implant irritation. During the second operation, the heterotopic ossification was not found to be the main mechanical cause of rotational limitation. Immediate postoperative elbow and forearm motions were full (Fig. 4).

### Follow-up and outcomes

Although wrist pain improved after the second operation, the patient developed a new clunking sensation within 3 weeks. Imaging demonstrated irreducible anterior dislocation of the radial head, indicating local proximal radioulnar joint instability. A third operation was therefore planned immediately and performed 4 weeks after the second operation. Annular ligament reconstruction using a palmaris longus autograft was performed to restore proximal stability (Fig. 5). At 1 year after the third operation, the patient reported mild residual pain with a numeric rating scale score of 1 to 2. Elbow motion was 135° of flexion and 0° of extension, forearm rotation was 55° of supination and 30° of pronation, and wrist motion was 60° of flexion and 70° of extension. Ulnar-sided wrist pain had substantially improved. Radiographs demonstrated maintained reduction of the radial head without recurrent dislocation, and the patient reported no recurrent clunking sensation or subjective instability. Thus, proximal radioulnar stability and ulnar-sided wrist pain improved, whereas substantial limitation of forearm rotation persisted.

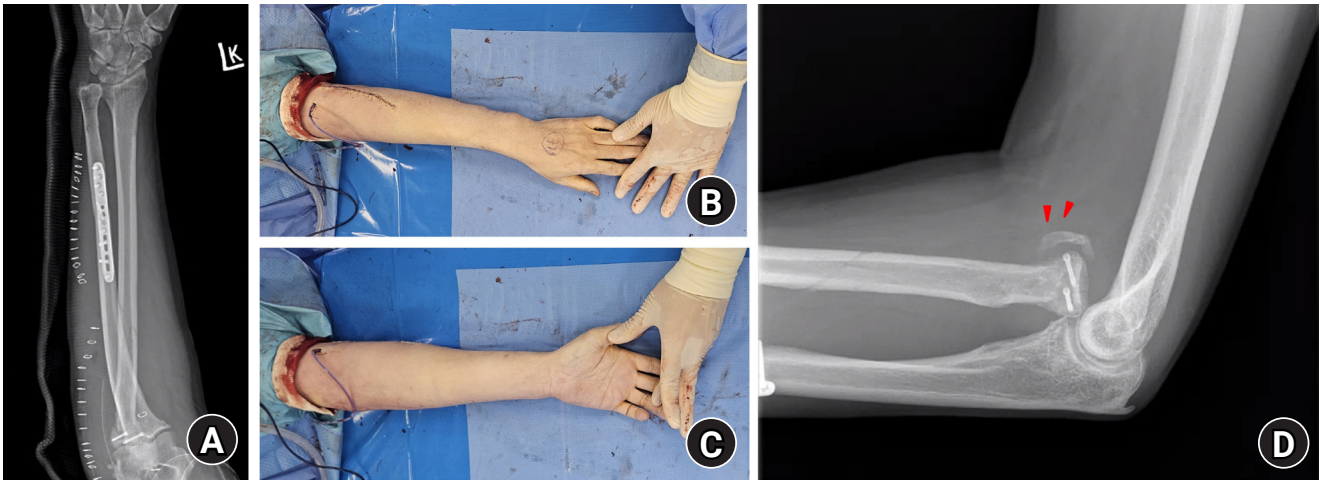



**Fig. 4.** Intraoperative and postoperative findings after the second operation, including proximal arthrolysis and diaphyseal ulnar shortening osteotomy. (A) Postoperative forearm radiograph showing diaphyseal ulnar shortening osteotomy. (B, C) Intraoperative assessment after proximal arthrolysis showing improved passive forearm rotation. (D) Postoperative lateral elbow radiograph showing anterior dislocation of the radial head (arrowheads).

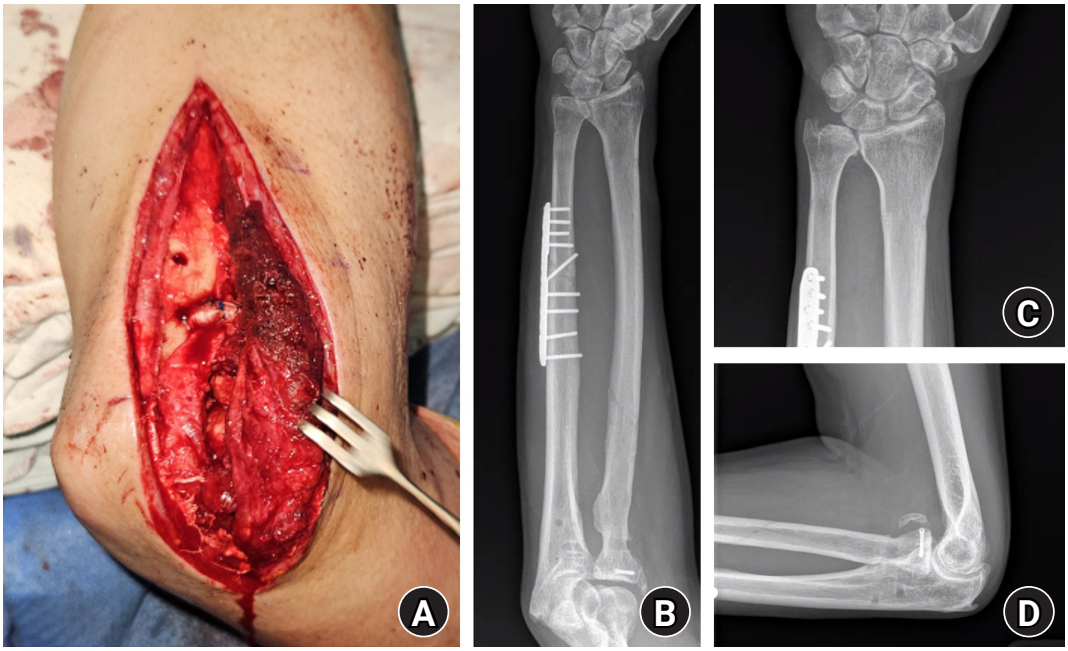



**Fig. 5.** Findings after the third operation. (A) Intraoperative photograph showing annular ligament reconstruction using a palmaris longus autograft. (B–D) Postoperative radiographs confirming reduction of the radial head.

## Discussion

Essex-Lopresti injury represents failure of the forearm as a biomechanical unit rather than an isolated injury of a single joint or ligament [1,2,4,5]. The present case illustrates a practical limitation in postoperative assessment: radiographic union of the radial head and apparent restoration of radial length after the index procedure did not ensure durable forearm balance. Ulnar-positive variance in this setting may reflect not only osseous radial shortening but also DRUJ alignment, forearm position during radiography, and abnormal longitudinal load transfer across the


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forearm. Therefore, radial head union alone should not be interpreted as evidence that longitudinal forearm stability has been restored.

### Why did instability progress despite multistructural index surgery?

A more compelling question raised by this case is why progressive instability developed despite multistructural initial management, including fixation of the radial head, temporary DRUJ pinning, arthroscopic TFCC repair, and suture-button augmentation of the interosseous membrane. One possible explanation is the uncertain role of suture-button augmentation itself. Clinical evidence supporting acute suture-button augmentation in Essex-Lopresti injury remains sparse, limited mainly to a case report in the acute setting and a small retrospective series in chronic instability [7,8]. Although these reports suggest that the technique may be feasible, they do not establish a standard reconstructive strategy [7,8]. In addition, the native CB is a broad ligamentous structure, and reproducing its rotational behavior with a focal suture-button construct remains challenging. Kholinne et al. [9] showed that the CB maintains relatively constant strain during forearm rotation and suggested that graft tensioning angle may influence reconstruction behavior. Therefore, construct-related technical factors, including nonstandardized graft orientation or tensioning, may have contributed in the present case.

Another possible contributor is that the temporary 1.2-mm DRUJ pin fixation itself may not have provided sufficiently rigid radioulnar stabilization. In this case, wrist and elbow flexion-extension motion was started at 6 weeks postoperatively, with active forearm rotation planned after pin removal at 8 weeks; however, pin breakage was noted at 7 weeks. This finding may be interpreted only as a possible marker of mechanical stress across the DRUJ, rather than direct evidence of construct failure or persistent longitudinal instability. Although the exact cause cannot be determined, this case suggests that failure may occur despite anatomically successful initial treatment and multistructural soft-tissue management.

### What should have been reconsidered before the second operation?

Importantly, unlike instability in a single joint, chronic longitudinal forearm instability may present with pain, weakness, and limited forearm rotation rather than excessive motion [1-3]. Therefore, the restricted rotation in this case may itself have been a symptom of persistent forearm instability, not simply a mechanical block around the proximal radius. Retrospectively, the increasing ulnar-positive variance and DRUJ widening before the second operation may also have represented persistent longitudinal forearm imbalance, and this possibility should have been considered before performing isolated balancing or release procedures.

This distinction is important because heterotopic ossification around the radial head was not found to be the main mechanical cause of rotational limitation at surgery. Therefore, simple release of the proximal radioulnar region could not be expected to solve the underlying problem. Instead, proximal arthrolysis, implant removal, and USO may have altered the balance of the forearm unit, although the individual contribution of each procedure cannot be determined in a single case. The subsequent irreducible anterior radial head dislocation may have reflected persistent longitudinal forearm imbalance, pre-existing proximal soft-tissue injury, iatrogenic destabilization during arthrolysis, or a combination of these factors. These possibilities are consistent with the concept that the forearm must be managed as an integrated unit rather than as separate joints. USO can still be useful in this setting, particularly when distal ulnar-sided wrist pain, positive ulnar variance, and secondary ulnocarpal impaction are the dominant complaints [6,10]. However, USO does not anatomically reconstruct the CB and therefore should be understood primarily as a balancing procedure rather than a definitive solution to persistent longitudinal instability. It may reduce distal symptoms, but it does not directly correct the underlying CB insufficiency. In addition, excessive reliance on ulnar shortening alone may theoretically alter load distribution across the proximal forearm and radiocapitellar articulation. For example, ulnar shortening performed proximal to the functional CB complex may have further reduced effective tension within the residual interosseous stabilizers.

### When should USO or CB reconstruction be considered?

Current strategies for interosseous membrane reconstruction remain diverse and incompletely validated. Various methods, including tendon graft reconstruction and suture-button–based techniques, have been described,

yet no single technique has gained universal acceptance [6,8,9]. This likely reflects not only the rarity of symptomatic chronic CB insufficiency, but also the fact that available procedures are invasive and biomechanically imperfect surrogates for a complex native structure. Thus, when incomplete healing of the interosseous membrane is suspected after acute treatment, the indication, timing, and method of CB reconstruction remain unresolved issues.

In the absence of high-level evidence, the author's interpretation is that the choice between USO and interosseous membrane reconstruction should be guided by the dominant clinical problem. When distal ulnar-sided wrist pain, positive ulnar variance, and secondary ulnocarpal impaction are the main findings without obvious signs of persistent instability or progressive radiographic imbalance, USO may be considered as a simpler salvage or balancing procedure [6,10]. In contrast, when persistent forearm instability is suggested by proximal symptoms such as elbow pain, functional weakness, painful clunking, or clear radioulnar dissociation, CB reconstruction may be the more rational consideration. This distinction is not evidence-based, but may provide a practical framework for decision-making in difficult cases.

This case has several practical implications. Even after multistructural initial management, balanced forearm mechanics may still fail to be restored in Essex-Lopresti injury. In the acute setting, a firm construct and sufficient postoperative protection may be more important than early rehabilitation, in addition to restoration of the bony stabilizers. When symptoms persist, the problem should be re-evaluated from the perspective of forearm biomechanics. USO helps balance dominant distal symptoms, whereas interosseous membrane reconstruction may be considered when persistent instability is strongly suspected.

The main strength of this report is that the serial operative course provided direct clinical insight into how each intervention may influence forearm balance over time. Its main limitation is that it is a single case without direct measurement of interosseous membrane healing, proximal soft-tissue integrity, or dynamic load transfer. Nevertheless, the case highlights a clinically important lesson: in Essex-Lopresti injury, radiographic fracture healing and apparent restoration of radial length may not be sufficient to ensure durable, balanced forearm mechanics.

## Article Information

### Author contributions
All the work was done by SeongJu Choi.

### Conflicts of interest
No potential conflict of interest relevant to this article was reported.

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Not applicable.

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None.

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# Reconstruction of a 20-cm tibial bone defect after recurrent fracture-related infection using the induced membrane technique and rhBMP-2 augmentation with limited autogenous bone availability: a case report

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Fracture-related infection (FRI) poses the combined challenges of infection control and reconstruction of critical-sized bone defects. These challenges are amplified in recurrent cases with severely limited autogenous bone availability. We report a 61-year-old male patient with recurrent right tibial FRI after multiple operations and a 20-cm segmental defect. Suspected residual infectious foci were mapped by comparing preoperative fluorodeoxyglucose positron emission tomography/computed tomography (PET/CT) with post-debridement CT and were evaluated using site-specific pre- and post-debridement cultures. After a second targeted debridement, all post-debridement cultures were negative, and no clinical or laboratory evidence of active infection was observed during a 2-week antibiotic-free interval. The defect was subsequently reconstructed using the induced membrane technique with 30 $cm^3$ of autogenous cancellous bone, 60 $cm^3$ of demineralized bone matrix, and 9 mg of recombinant human bone morphogenetic protein-2 (rhBMP-2) delivered on a 20 $cm^3$ hydroxyapatite carrier. Radiographic union was achieved, and no clinical evidence of infection recurrence was observed at 1 year. This case suggests the feasibility of combining PET/CT- and culture-guided anatomically targeted debridement with rhBMP-2-augmented induced membrane reconstruction when autogenous graft volume is severely limited.

**Level of evidence:** V.

**Keywords:** Fracture-related infection; Bone morphogenetic protein 2; Tibial fractures; Limb salvage; Case reports

## Case Report

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## Introduction

Fracture-related infection (FRI) represents a major challenge in orthopedic trauma surgery, associated with significant morbidity, prolonged treatment, and profound socioeconomic consequences [1,2]. Despite advances in surgical and antimicrobial strategies, FRI continues to cause significant functional impairment and, in severe cases, limb amputation [3,4]. Management remains challenging due to two interrelated but compounding problems. First, infection recurrence persists, with reported rates of recurrence or treatment failure of 25%–38% despite protocolized surgical management [5,6]. Second, repeated radical debridement, necessary for adequate infection management, inevitably results in bone loss that can culminate in criti-

cal-sized defects [7]. Consequently, management requires both infection control and complex skeletal reconstruction, rendering FRI management a dual and formidable challenge.

Recurrence of FRI following reconstruction is particularly devastating, requiring repeated radical resection that can enlarge an already critical-sized defect. Management of recurrent cases is further complicated when autogenous bone sources have been exhausted by prior procedures, leaving the surgeon with limited reconstructive options. However, before any reconstructive strategy can be undertaken, a prerequisite challenge must be addressed: accurate identification and thorough clearance of residual infection are essential.

This case illustrates a convergence of challenges: recurrent FRI with an enlarging tibial bone defect and substantial depletion of autogenous bone graft sources. The objective of this case report is to describe the surgical strategy employed to achieve infection clearance and skeletal reconstruction under severely depleted biological conditions, with the aim of serving as a practical reference for surgeons encountering a similarly complex convergence of recurrent FRI, critical-sized bone defect, and extremely limited autogenous bone donor sites.

## Case report

### Ethics statement

Written informed consent was obtained from the patient for the publication of this case report and all accompanying clinical images.

### Patient information

A 61-year-old male patient was referred to our institution for management of right tibial FRI. Surgical history included extensive autologous bone harvesting from the bilateral anterior iliac crests, left posterior iliac crest, and the right fibula ~15 years earlier for the treatment of left tibial FRI. Six years prior, he sustained a right tibial shaft fracture and subsequently underwent multiple revision surgeries at an outside institution, resulting in FRI in the right tibia. Due to repetitive treatment failure and infection recurrence, he was transferred to our center for further care. At our institution, a pre- and post-debridement, culture-based staged surgical protocol was initiated, comprising three consecutive debridement procedures, with concomitant anterolateral thigh free-flap coverage to address soft-tissue deficiency. Following three staged debridements, negative post-debridement cultures, and anterolateral thigh free-flap coverage, the defect was reconstructed using the maximum safely obtainable volume of autogenous bone supplemented with recombinant human bone morphogenetic protein-2 (rhBMP-2) and demineralized bone matrix (DBM) (Fig. 1). Four months after the initial reconstruction, infection recurred, creating the combined challenge of managing recurrent FRI and reconstructing a critical-sized defect with severely limited remaining autogenous graft availability (Fig. 2).

### Infection management strategy

Upon confirmed recurrence, preoperative fluorodeoxyglucose positron emission tomography/computed tomography (FDG-PET/CT) was analyzed in conjunction with prior magnetic resonance imaging (MRI) obtained at initial presentation. Comparative review showed that FDG uptake was greatest in the proximal tibia at previous external-fixator pin sites, with additional uptake in the reconstructed diaphyseal segment. Because FDG avidity is not specific for infection, these regions were regarded as suspected residual foci and were correlated with operative findings and site-specific cultures. The proximal findings raised concern for incomplete prior debridement rather than proving it on imaging alone (Fig. 2).

The first re-debridement was subsequently performed, with removal of the intramedullary nail and all previously grafted materials, followed by targeted resection of the FDG-avid lesion of the proximal tibia as identified via FDG-PET/CT. Intraoperative pre- and post-debridement cultures were obtained to identify the causative organism and assess debridement adequacy [5,8]. Following this procedure, post-debridement CT was systematically compared with the preoperative FDG-PET/CT. This comparison revealed anatomical regions that demonstrated FDG uptake on the preoperative scan but appeared incompletely resected on the post-debridement CT. Positive post-debridement culture at corresponding sites confirmed residual infection. These combined imaging and microbiological findings identified specific foci requiring further resection (Fig. 3).

At recurrence, extensive purulent drainage and wide-

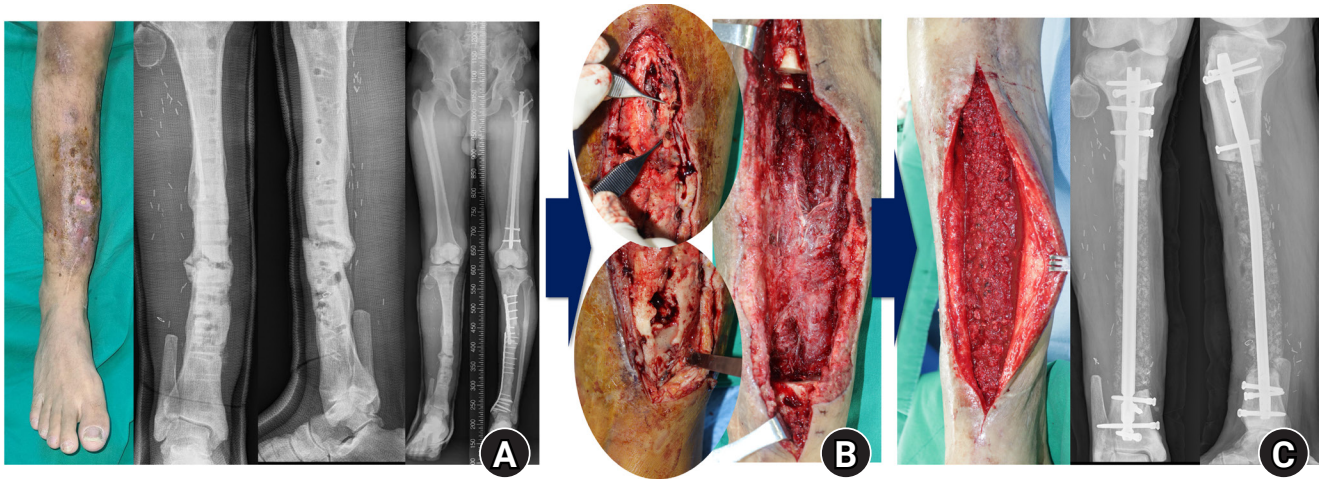



**Fig. 1.** Initial clinical presentation, intraoperative findings, and postoperative radiograph following primary bone reconstruction. (A) Clinical photograph and plain radiographs at initial presentation. Examination revealed soft-tissue breakdown. Radiographs showed extensive sclerotic bone changes, fracture nonunion, and valgus malalignment of the tibial shaft. Both iliac crests and the right fibula had been previously harvested for the management of left tibial fracture-related infection, substantially limiting the volume available from these donor sites. (B) Intraoperative photographs during debridement. Extensive devitalized bone and intraosseous pus drainage were identified at the time of surgery. Following segmental resection of the infected and necrotic bone, three consecutive debridement procedures, guided by post-debridement culture results, were performed to achieve microbiological clearance before proceeding to the subsequent stage. (C) Postoperative radiograph following the first bone reconstruction procedure, demonstrating reconstruction using the induced membrane technique with autogenous bone harvested from the ipsilateral iliac crest and posterior superior iliac spine, combined with recombinant human bone morphogenetic protein-2 and demineralized bone matrix.

spread soft-tissue involvement were present. Given the risk of unnecessary soft-tissue sacrifice with immediate re-debridement, intravenous antibiotic therapy was first administered to optimize the soft-tissue condition and maximize soft-tissue preservation prior to the second surgical intervention. Following 6 weeks of culture-directed systemic antibiotic therapy and a 2-week antibiotic-free interval, a second targeted re-debridement was performed to address residual foci identified by combined imaging and microbiological analyses. Second post-debridement CT confirmed complete excision of all regions that had shown FDG uptake on the preoperative PET/CT, and repeat post-debridement cultures were negative, indicating that the planned debridement had been achieved with both radiological and microbiological clearance (Fig. 3).

Culture-directed antibiotic therapy was continued for 6 weeks, followed by a 2-week antibiotic-free interval. Serial inflammatory markers monitored during and after this period confirmed the absence of recurrence before proceeding to the next stage. Antibiotic selection was guided by the evolving microbiological profile across the two re-debridements, in consultation with the infectious disease department. After the first re-debridement, selected post-debridement samples remained positive for methicillin-sensitive *Staphylococcus aureus* (MSSA) or methicillin-resistant *S. aureus* (MRSA), indicating that additional resection was required. At the second re-debridement, two pre-debridement samples yielded MSSA, whereas all post-debridement cultures showed no growth. Vancomycin was used after the first re-debridement to cover MRSA, and cefazolin was used after the second procedure on the basis of the MSSA isolates and the absence of MRSA in the second set of cultures. Microbiological findings and antibiotic regimens are summarized in Table 1.

### Reconstruction of a 20-cm tibial bone defect in the setting of depleted autogenous bone graft sources

After completion of culture-directed antibiotic therapy and a 2-week antibiotic-free interval, the absence of clinical signs of infection recurrence, normalization or stability of inflammatory markers, and negative post-debridement cultures supported proceeding to reconstruction. Definitive fixation was achieved with intramedullary nailing, followed by insertion of an antibiotic-loaded cement


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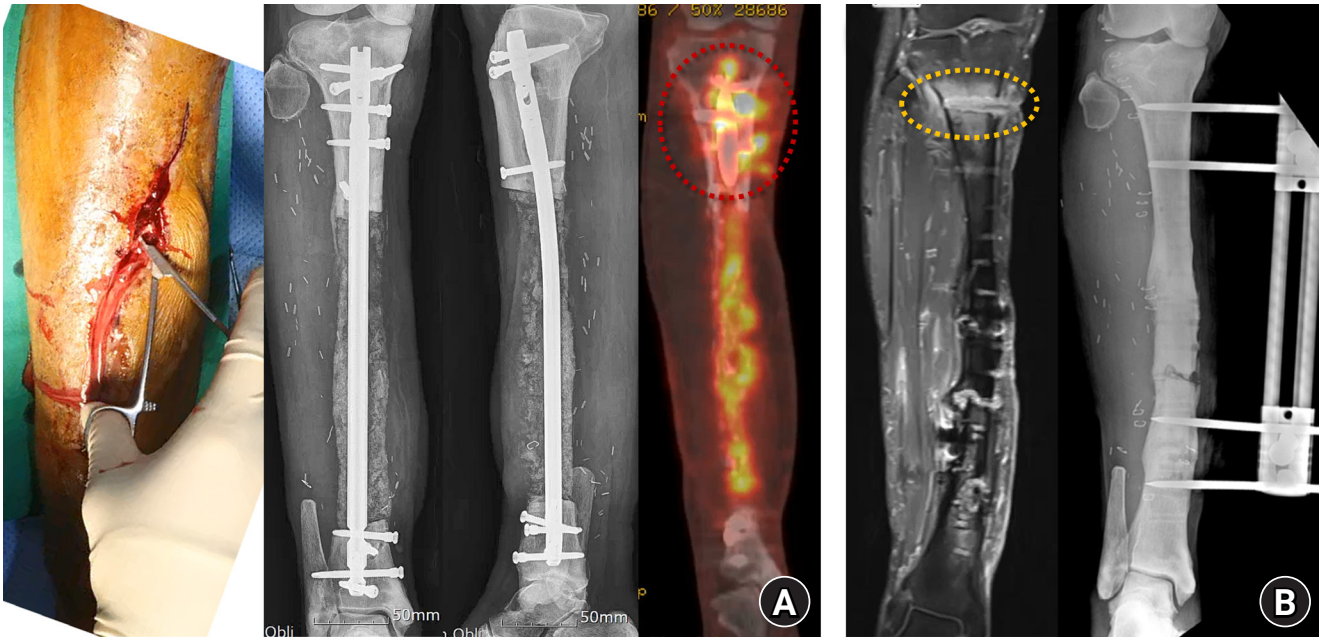



**Fig. 2.** Imaging findings at infection recurrence and comparison with prior imaging. (A) Clinical photograph showing active pus drainage, confirming infection recurrence. Plain radiograph at 4 months post-reconstruction and procedure at the time of confirmed infection recurrence. FDG-PET/CT image obtained at the time of infection recurrence. The red dotted circle highlights FDG uptake localized to the proximal tibial region and diaphyseal segment of the prior reconstruction, identifying these as the predominant sites of residual infection. (B) MRI obtained at the patient's initial presentation to our institution and plain radiograph from the referring institution, both before fracture-related infection management. MRI shows signal changes at prior external-fixator pin sites in the proximal tibia (yellow dotted circle), corresponding to the area of predominant FDG uptake on PET/CT in (A). Comparative analysis confirms that the proximal tibial region, where only curettage had previously been performed, was the primary focus of infection recurrence. FDG, fluorodeoxyglucose; PET, positron emission tomography; CT, computed tomography; MRI, magnetic resonance imaging.

spacer into the defect according to the induced membrane technique in preparation for staged bone reconstruction 6 weeks later. Partial weight-bearing with crutch assistance was initiated, and rehabilitation was commenced. Bone reconstruction was performed 6 weeks after spacer insertion.

At the second stage, the induced membrane was incised, and the cement spacer was removed. The estimated volume of the bone defect was approximately 120.75 $cm^3$, derived from CT by averaging the cross-sectional areas of the proximal and distal remnant tibial segments and multiplying by the length of the defect. Because the autogenous donor sites had been substantially depleted by repeated prior harvesting, only 30 $cm^3$ of cancellous bone was harvested from bilateral iliac crests, which was markedly insufficient for a defect of this size. To address this limitation, 9 mg of rhBMP-2 with 20 $cm^3$ of a hydroxyapatite (HA) carrier (Novosis; CGBio) was used as the principal osteoinductive component to compensate for the substantially insufficient autogenous bone (off-label use, with written informed consent obtained from the patient). In addition, 60 $cm^3$ of DBM was used as a volume expander. The graft composite, amounting to approximately 110 $cm^3$ in total, was placed within the induced membrane chamber, followed by membrane closure (Fig. 4). The implanted volume was thus approximately 10 $cm^3$ less than the estimated defect volume, a result attributable to both the limited autogenous bone available and the already high proportion of volume expander in the composite.

### Follow-up and outcomes

Following bone reconstruction, crutch-assisted partial weight-bearing ambulation began 2 weeks postoperatively. Serial radiographs demonstrated progressive consolidation of the grafted segment. At 6 months, consolidation of the grafted bone had progressed to bridge at least three of four cortices on orthogonal radiographs, meeting the prespec-

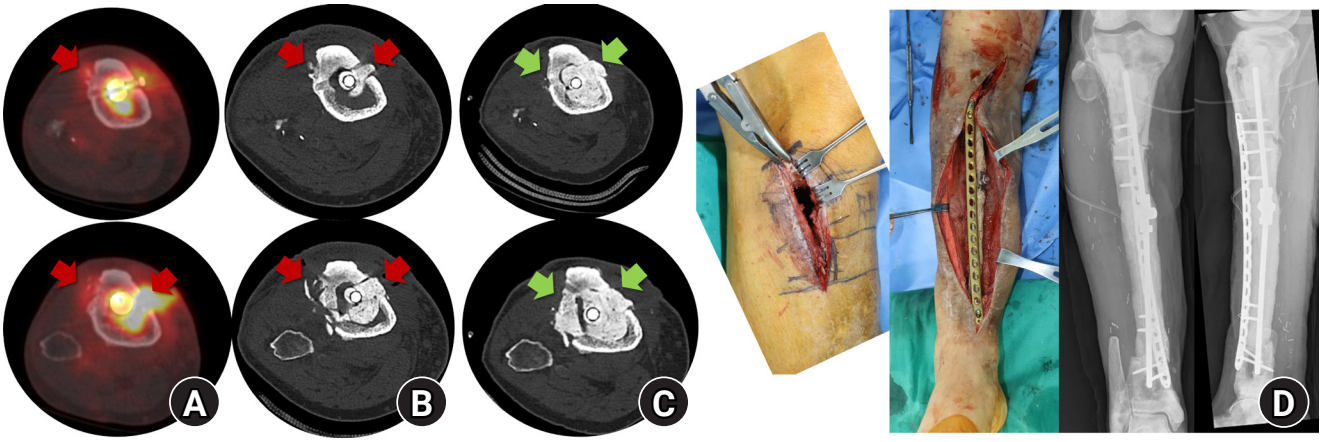



**Fig. 3.** Sequential imaging-guided debridement strategy for infection recurrence: comparative analysis of FDG-PET/CT and post-debridement CT findings. (A) Preoperative FDG-PET/CT images obtained at the time of infection recurrence, showing the distribution and anatomical localization of FDG-avid lesions, which guided subsequent targeted debridement. (B) Post-debridement CT images following the first re-debridement procedure. Red arrows indicate anatomical regions that demonstrated FDG uptake on preoperative PET/CT but were identified as incompletely resected on post-debridement CT, representing residual infectious foci requiring further targeted resection. (C) Post-debridement CT after the second re-debridement. Green arrows indicate areas previously identified as inadequately resected on the post-first-debridement CT (red arrows in [B]), now demonstrating complete excision of the residual infectious foci. Comparison with preoperative PET/CT confirmed complete resection of the previously identified FDG-avid regions. (D) Intraoperative photograph and postoperative radiograph from the second re-debridement, showing targeted additional resection of the proximal tibial region guided by the combined imaging and microbiological analysis. The defect was filled with an antibiotic-loaded polymethylmethacrylate cement spacer, an antibiotic-loaded cement-coated rod was inserted into the intramedullary canal, and a 3.5-mm metaphyseal locking plate was employed for provisional fixation. FDG, fluorodeoxyglucose; PET, positron emission tomography; CT, computed tomography.

ified radiographic criterion for union. At 1-year follow-up, complete consolidation of the reconstructed tibial segment was confirmed radiographically, with no clinical or laboratory evidence of infection recurrence. No rhBMP-2–related adverse events, including heterotopic ossification, seroma, or excessive soft-tissue swelling, were observed throughout the follow-up period. The patient fully resumed the activities of daily living without the use of assistive devices (Figs. 5, 6). A residual limb-length discrepancy of 1.7 cm was noted at final follow-up; however, this did not require lengthening intervention and did not impair the patient's return to daily activities. The patient's Lower Extremity Functional Scale score was 74 of a possible 80, indicating minimal functional limitation.

## Discussion

This case report highlights two clinically significant achievements in the management of an extreme FRI scenario. First, in a patient with multiple recurrences of FRI despite repeated surgical intervention, infection was successfully managed through a systematic, image- and culture-guided debridement strategy. Integration of preoperative FDG-PET/CT with serial post-debridement CT, combined with a stringent pre- and post-debridement culture protocol, enabled precise anatomical localization of the residual infectious focus, objective verification of debridement completeness, and confirmation of microbiological clearance prior to reconstruction. This approach provides a novel framework for managing recurrent FRI when conventional imaging fails to reliably identify the source of infection recurrence. Second, and of greater reconstructive significance, this case represents, to the best of our knowledge, one of the largest tibial bone defects following FRI reconstructed by the induced membrane technique reported to date. In prior infection series, segmental tibial defects have generally ranged from approximately 6 to 15 cm [9-11], and although a tibial defect of 20 cm has been reconstructed in the aseptic setting [12], such an extensive defect has not previously been described in the tibia in the context of infection. Post-infection defects of comparable magnitude have to our knowledge been


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**Table 1.** Microbiological culture results and antibiotic regimens from the first and second debridement procedures

| Variable | | Pre-debridement culture | Post-debridement culture |
|---|---|---|---|
| 1st Debridement | IMP 4 | No growth | No growth |
| | IMP 3 | MRSA | No growth |
| | IMP 2 | MSSA | No growth |
| | IMP 1 | MSSA | MSSA |
| | EMP lateral 1 | MSSA | MSSA |
| | EMP lateral 2 | MSSA | No growth |
| | EMP lateral 3 | MSSA | No growth |
| | EMP lateral 4 | MRSA | No growth |
| | EMP lateral 5 | MSSA | No growth |
| | EMP middle | MSSA | No growth |
| | EMP medial 1 | MSSA | No growth |
| | EMP medial 2 | MSSA | MRSA |
| | Center proximal | MSSA | Not separately sampled[a] |
| | Center 1 | MSSA | MSSA |
| | Center 2 | MSSA | No growth |
| | Center anterior | MSSA | Not separately sampled[a] |
| | Center posterior | MSSA | Not separately sampled[a] |
| | Center distal | MSSA | Not separately sampled[a] |
| | IMD | MSSA | MSSA |
| | EMD | MSSA | No growth |
| | Pus 1 | MSSA | NA[b] |
| | Pus 2 | MSSA | NA[b] |
| | Pus 3 | MSSA | NA[b] |
| 2nd Debridement | IMP 4 | No growth | No growth[c] |
| | IMP 3 | No growth | No growth |
| | IMP 2 | MSSA | No growth |
| | IMP 1 | No growth | No growth |
| | EMP lateral 1 | No growth | No growth |
| | EMP lateral 2 | No growth | No growth |
| | EMP lateral 3 | No growth | No growth |
| | EMP lateral 4 | No growth | No growth |
| | EMP lateral 5 | No growth | No growth |
| | EMP middle | No growth | No growth |
| | EMP medial | MSSA | No growth |
| | Center 1 | No growth | No growth |
| | IMD | No growth | No growth |
| | EMD | No growth | No growth |

Antibiotic regimen after 1st debridement, Vancomycin × 6 wk → 2-wk drug holiday; Antibiotic regimen after 2nd debridement, Cefazolin × 6 wk → 2-wk drug holiday.
IMP, intramedullary proximal; MRSA, methicillin-resistant *Staphylococcus aureus*; MSSA, methicillin-sensitive *Staphylococcus aureus*; EMP, extramedullary proximal; IMD, intramedullary distal; EMD, extramedullary distal.
[a]Not separately sampled; this site was included in the center 1 and center 2 post-debridement cultures. [b]Not applicable; no pus was present, so no specimen could be obtained. [c]All second post-debridement cultures were negative.

reported only in the femur [5]. This anatomical distinction is noteworthy, as the tibia is inherently more difficult to reconstruct: unlike the well-vascularized, muscle-enveloped femur, the anteromedial tibia is covered by only a thin, poorly vascularized soft-tissue layer, which compromises graft incorporation and heightens susceptibility to persistent or recurrent infection [8]. Notably, reconstruction was performed under conditions of near-complete depletion of autogenous bone graft sources, as the available donor sites had been extensively harvested by prior surgeries for bilateral tibial FRI, leaving only 30 $cm^3$ of autogenous bone available.

The reconstruction strategy in this case was supported by accumulating evidence for the use of rhBMP-2 within the induced membrane technique. From a biological standpoint, the adequacy of graft bioactivity is critically dependent on the proportion of autogenous bone within the graft mixture. Cho et al. [13] demonstrated that a higher percentage of DBM in the graft mixture was inversely correlated with early volumetric change, suggesting that excessive reliance on bone substitutes with limited osteoinductive and osteogenic properties leads to increased early graft resorption. This principle is further supported by Masquelet et al., who recommend a graft composition of at least 70% autograft and 30% volume expander [14]. In the present case, the available autogenous bone volume of 30 $cm^3$ was substantially insufficient relative to the estimated defect volume of 120.75 $cm^3$, and the proportion of autograft was substantially below this recommended level, placing this reconstruction at high biological risk for graft resorption and delayed consolidation. In this context, rhBMP-2 served as the principal osteoinductive agent rather than a mere adjunct, compensating for the substantially deficient autograft volume and enhancing the overall osteoinductive potential of the graft mixture [15-17]. Son et al. [18] demonstrated that rhBMP-2 with a HA carrier in the induced membrane technique significantly increased bone density, corticalization, and shortened time to union compared with the induced membrane technique alone. Subsequently, the same group demonstrated in a preclinical rabbit model that rhBMP-2 with a HA/β-tricalcium phosphate/hydrogel carrier, used as a complete replacement for autogenous bone graft, achieved radiographic, biomechanical, and histological outcomes comparable or superior to autogenous bone graft alone within the in-

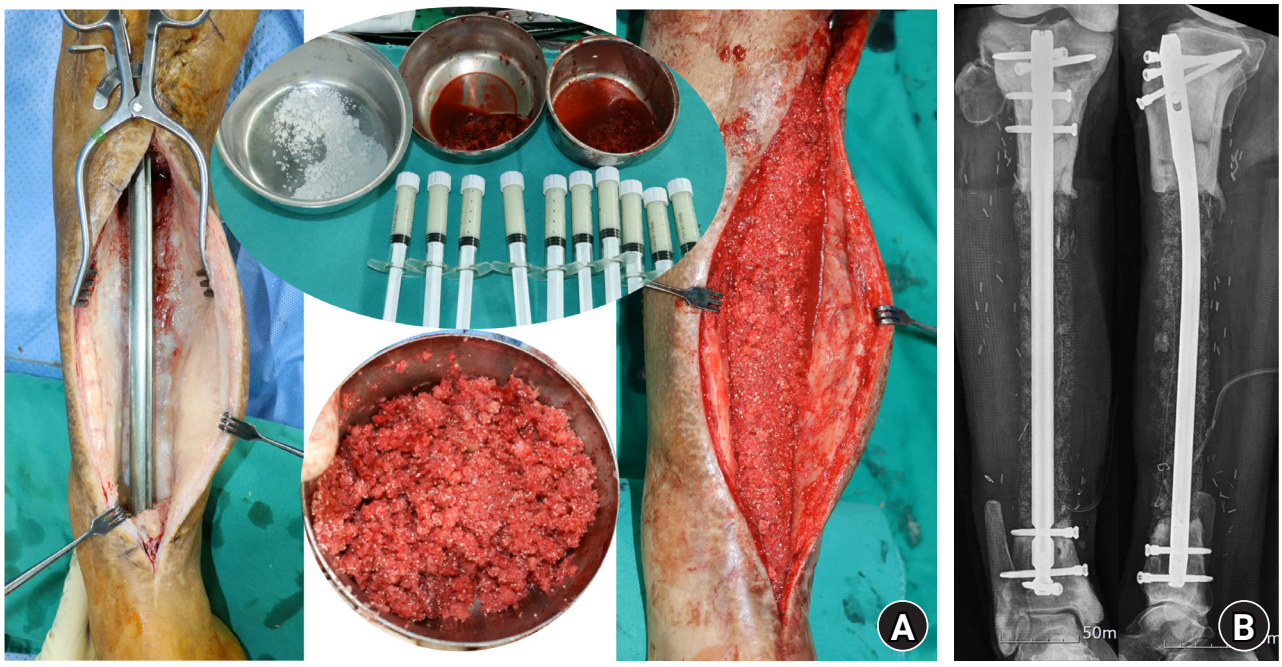



**Fig. 4.** Intraoperative photographs and postoperative plain radiographs of the bone reconstruction procedure. (A) Intraoperative photographs showing bone reconstruction using the induced membrane technique. Only 30 $cm^3$ of autogenous cancellous bone could be harvested from bilateral iliac crests, previously subjected to repeated harvesting, reflecting near-complete depletion of available autogenous bone. To address the 20-cm tibial bone defect, 9 mg of rhBMP-2 with a hydroxyapatite carrier was used as the primary osteoinductive supplement to compensate for the insufficient autogenous bone. Additionally, 60 $cm^3$ of DBM served as a volume expander to fill the defect. (B) Postoperative plain radiographs following the bone reconstruction procedure. rhBMP-2, recombinant human bone morphogenetic protein-2; DBM, demineralized bone matrix.

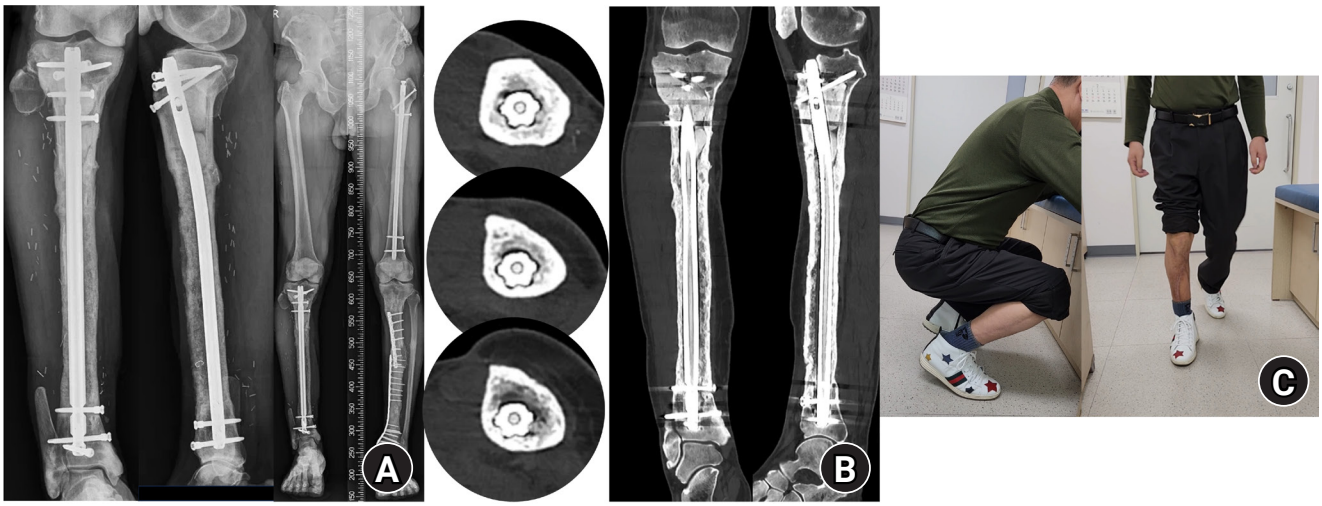



**Fig. 5.** Radiographic and clinical outcomes at 1 year following bone reconstruction. (A) Plain radiographs demonstrating complete consolidation of the reconstructed tibial segment and bone union, with no evidence of infection recurrence. (B) Computed tomography images confirming complete cortical bridging and consolidation of the grafted segment across all planes, consistent with solid bone union. (C) Clinical photograph demonstrating independent ambulation and performance of the illustrated functional activities at 1 year postoperatively.


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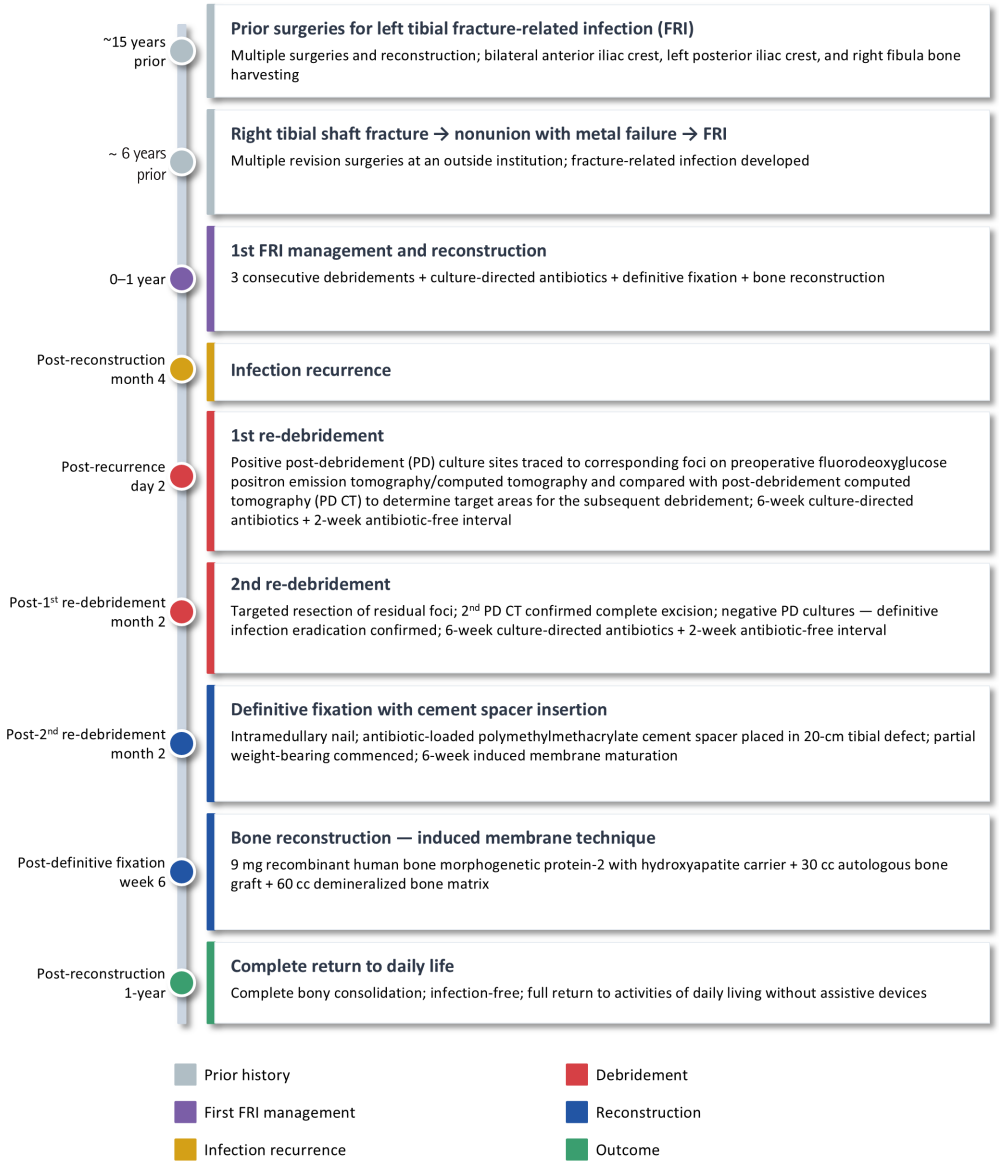



**Fig. 6.** Chronological treatment timeline of the reported case.

duced membrane technique, establishing that a fully autograft-free strategy can be a viable reconstructive option [15]. The successful consolidation achieved in the present case further corroborates these findings, demonstrating that rhBMP-2 can effectively overcome the biological limitations imposed by critically insufficient autogenous bone, thereby potentially supporting graft incorporation even in the setting of a 20-cm critical-sized tibial defect.

The decision to proceed with the induced membrane technique with rhBMP-2, rather than other established reconstructive strategies, was also driven by patient-specific anatomical constraints. For a tibial defect of this magnitude, vascularized fibular bone graft and bone transport via distraction osteogenesis are commonly considered alternatives; however, neither was applicable in this case. Vascularized fibular graft was not feasible: the ipsilateral fibula had already been harvested for contralateral tibial reconstruction, and harvesting the contralateral fibula carried an unacceptable risk of peri-implant fracture given the poor bone quality of the previously reconstructed tibia. Bone transport was likewise excluded. With only 94 mm of proximal and 44 mm of distal tibial bone remaining, a proximal

corticotomy would have left a residual proximal segment insufficient to achieve fixation capable of resisting the proximal deforming forces during transport. Stable fixation of both the proximal and distal segments—each conventionally secured with multiple fixation elements above and below the corticotomy—is a prerequisite for reliable distraction and docking [19], and the markedly limited length of the remaining proximal segment was judged inadequate for this purpose. Moreover, transport of a 20-cm defect would have required a prolonged distraction and consolidation period during which weight-bearing and rehabilitation would be substantially restricted, raising serious doubt as to whether this patient could ultimately regain satisfactory function. For these reasons, the induced membrane technique was selected as the reconstructive strategy. This approach provides sufficient stability throughout the reconstruction period through intramedullary nail fixation and, importantly, permits partial weight-bearing from the time of nailing, thereby allowing early rehabilitation.

The safety of rhBMP-2 in a previously infected site warrants acknowledgment. Available evidence suggests that rhBMP-2 can be used safely once infection has been definitively eradicated, with no evidence that it promotes reinfection [20,21]. Preclinical data further indicate that rhBMP-2 can partially overcome the inhibitory effects of infection on fracture healing without promoting pathogen persistence or biofilm formation [22,23]. Heterotopic ossification is a recognized concern with high-dose rhBMP-2 delivered on absorbable collagen sponges, which release nearly the entire protein load within the first day. The HA carrier used in this case provides sustained release over several weeks, and heterotopic ossification has not been reported with this delivery system. In a multicenter prospective trial of 81 patients treated with an HA carrier-based rhBMP-2 system for acute fractures with bone defects, no ectopic ossification, systemic complications, or severe inflammatory responses occurred, and the only device-related adverse event was a single localized seroma [17]. A prospective case series of long-bone nonunion treated with rhBMP-2 and HA granules likewise reported no adverse effects or antibody formation [24], and preclinical work has shown early bone regeneration with minimal inflammation and no ectopic ossification using the same carrier [25]. In the present case, no heterotopic ossification, seroma, local swelling, wound complication, or other adverse event attributable to rhBMP-2 was observed throughout the 1-year follow-up, and no infection recurrence occurred. rhBMP-2 had been grafted only after adequate infection management was confirmed prior to reconstruction—based on negative post-debridement cultures, resection of all lesions showing FDG uptake on preoperative PET/CT as verified by post-debridement CT, and the absence of elevated inflammatory markers and clinical signs of recurrence after an antibiotic-free interval. Nonetheless, as a single case, this report cannot establish the safety profile of rhBMP-2 in this setting, and its use for a critical-sized post-infection tibial defect represented off-label use, of which the patient was informed and provided written consent.

### Limitations

This study has several limitations. The primary limitation is its single case report design, which precludes statistical inference and limits the generalizability of the findings. However, the convergence of recurrent FRI, critical-sized bone defect, and extremely limited autogenous bone donor sites represents an exceptionally rare clinical scenario; given its rarity, a well-documented single case report may nonetheless serve as a valuable practical guide for surgeons confronting this challenging situation. In addition, the present outcome is based on a follow-up period of 1 year; accordingly, the possibility of late infection recurrence cannot be excluded, and longer-term follow-up is warranted to confirm the durability of the infection-free outcome. Third, rhBMP-2 was not used in isolation: it was combined with autogenous cancellous bone, DBM, an induced membrane, stable fixation, and soft-tissue coverage. The contribution of rhBMP-2 alone therefore cannot be isolated from these concurrent factors, and the successful consolidation should be interpreted as supporting the feasibility of the combined strategy rather than proving the efficacy of rhBMP-2. Nonetheless, given that only 30 $cm^3$ of autogenous bone could be obtained from substantially depleted donor sites—far below the volume required for a 20-cm critical-sized tibial defect—it is difficult to conceive that reconstruction of a defect of this magnitude could have been achieved without the osteoinductive contribution of rhBMP-2. Fourth, regarding the infection management protocol, the use of post-debridement culture-based staging has been described and validated in prior studies, and its utility is supported by existing literature [5,8]. However,


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the integration of preoperative FDG-PET/CT with serial post-debridement CT as a tool for anatomically targeting residual infectious foci represents a less-established approach. It should also be noted that FDG-PET/CT cannot definitively confirm the presence of infection, as increased FDG uptake is not specific to infection and may also reflect inflammation, postoperative changes, or other non-infectious processes. Accordingly, in the present study, the anatomical extent of infection was ultimately determined on the basis of culture-positive areas rather than imaging findings alone, with FDG-PET/CT and serial post-debridement CT serving to guide anatomical localization rather than to establish a definitive diagnosis. Further studies with larger case series are therefore warranted to confirm the utility of this imaging-based localization approach. Finally, the optimal dose of rhBMP-2 relative to the defect length or volume remains undefined, and further studies are warranted to establish the appropriate amount of rhBMP-2 per unit of bone defect to guide reproducible and standardized application.

### Patient perspective

Having undergone multiple operations at other institutions without success, the patient had been faced with the prospect of amputation. He expressed profound satisfaction that his leg could ultimately be salvaged and that he was able to return to full, unrestricted daily activity.

### Adverse and unanticipated events

No adverse or unanticipated events occurred during treatment or throughout the follow-up period.

### Conclusions

In this patient, recurrent FRI was managed through an image- and culture-guided debridement strategy, followed by reconstruction of a 20-cm tibial defect by the induced membrane technique augmented with rhBMP-2, despite severely limited autogenous bone availability resulting from repeated prior debridement and grafting. At 1 year, complete consolidation had been achieved with no clinical evidence of infection recurrence. To our knowledge, this represents one of the largest post-FRI tibial defects reported to date.

## Article Information

### Author contributions

All the work was done by Whee Sung Son.

### Conflicts of interest

No potential conflict of interest relevant to this article was reported.

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### Data availability

Not applicable.

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### Supplementary materials

None.

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JMT Journal of Musculoskeletal Trauma

# Instructions for authors

Enacted from January 1, 1988
Last revision: December 1, 2025

## 1. GENERAL INFORMATION

The *Journal of Musculoskeletal Trauma* is the official publication of the Korean Orthopaedic Trauma Association (KOTA), and is published in academic collaboration with the Thai Orthopaedic Trauma Society (TOTS) and the Taiwan Orthopaedic Trauma Association (TOTA) as Affiliated Societies. It is an international, peer-reviewed, open-access journal dedicated to advancing the science, education, and clinical care of musculoskeletal trauma. The journal was first launched in 1988 and is published quarterly on the 25th of January, April, July, and October. As of October 2024, the official language of the journal has been changed to English.

The journal covers a wide range of topics related to musculoskeletal injuries, including but not limited to: prevention, diagnosis, treatment, and rehabilitation of fractures, dislocations, and soft tissue injuries of both the extremities and the axial skeleton; advances in surgical techniques, implants, and prosthetic devices; biomechanical and biological research related to trauma and tissue healing; rehabilitation strategies for functional recovery; and clinical and translational research bridging basic science and clinical practice.

We invite submissions of original articles, reviews, case reports, technical notes, letters to the editor, and editorials that contribute to the advancement of musculoskeletal trauma care. Manuscripts submitted to JMT should be prepared according to the following instructions. The journal adheres to the Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly Work in Medical Journals (http://www.icmje.org/icmje-recommendations.pdf) from the International Committee of Medical Journal Editors (ICMJE).

## 2. ARTICLE PROCESSING CHARGE

There are no author fees for manuscript processing or publication in the journal, as all costs are covered by the publisher, the Korean Orthopaedic Trauma Association, unless the policy changes. Therefore, it is a platinum open-access journal.

## 3. RESEARCH AND PUBLICATION ETHICS

The journal adheres to the guidelines for research and publication described in the Committee on Publication Ethics (COPE) Guidances (https://publicationethics.org/resources/guidelines) the ICMJE Recommendations (https://www.icmje.org), and the Good Publication Practice Guideline for Medical Journals (https://www.kamje.or.kr/board/view?b_name=bo_publication&bo_id=14). Furthermore, all processes addressing research and publication misconduct shall follow the flowcharts of COPE (https://publicationethics.org/resources/flowcharts). Any attempts to duplicate publications or engage in plagiarism will lead to automatic rejection and may prejudice the acceptance of future submissions.

### Statement of Human and Animal Rights

Clinical research should be conducted in accordance with the World Medical Association's Declaration of Helsinki (https://www.wma.net/what-we-do/medical-ethics/declaration-of-helsinki/). Any investigations involving humans and animals should be approved by the Research Ethics Committee (REC) or the Institutional Review Board (IRB) and Animal Care Committee, respectively, of the institution where the experiment was performed. JMT will not consider any studies involving humans or animals without appropriate approval. Such approval, along with the approval number and the name of the IRB or REC institution, should be stated in the Methods section of the manuscript. Informed consent must be obtained from patients participating in clinical investigations, unless waived by the IRB. In the case of an animal study, a statement should be provided indicating that the experimental procedures, such

as the breeding and the use of laboratory animals, was approved by the REC of the institution where the experiment was performed or that it does not violate the rules of the REC of the institution or the National Institutes of Health (NIH) Guide for the Care and Use of Laboratory Animals (Institute of Laboratory Animal Resources, Commission on Life Sciences, National Research Council). The authors should preserve raw experimental study data for at least 1 year after the publication of the paper and should present this data if required by the Editorial Board.

### Protection of Privacy, Confidentiality, and Written Informed Consent

The ICMJE has recommended the following statement for the protection of privacy, confidentiality, and written informed consent: The rights of patients should not be infringed without written informed consent. Identifying details (patients' names, initials, hospital numbers, dates of birth, or other personal or identifying information, protected healthcare information) should not be published in written descriptions. Images of human subjects should not be used unless the information is essential for scientific purposes and explicit permission has been given as part of the consent. For individuals who cannot provide consent independently, including those from vulnerable populations—such as minors, the elderly, racial or ethnic minorities, individuals with certain health conditions, or those who are socioeconomically disadvantaged—consent should be obtained from a legally authorized representative or parent/guardian. Even where consent has been given, identifying details should be removed if they are not essential. If identifying characteristics are altered to protect anonymity, authors should provide assurances that such alterations do not distort scientific meaning. If consent has not been obtained, it is generally not sufficient to anonymize a photograph simply by using eye bars or blurring the face of the individual concerned.

### Conflict of Interest

Authors are responsible for disclosing any financial support or benefit that might affect the content of the manuscript or might cause a conflict of interest. When submitting the manuscript, the author must attach a conflict of interest statement (https://e-jmt.org/authors/copyright_transfer_agreement.php). All authors should disclose their conflicts of interest, i.e., (1) financial relationships (such as employment, consultancies, stock ownership, honoraria, or paid expert testimony), (2) personal relationship, (3) academic competition, and (4) intellectual passion. These conflicts of interest must be included as a footnote on the title page. Each author should certify the disclosure of any conflict of interest with their signature.

### Originality, Plagiarism, and Duplicate Publication

Redundant or duplicate publication refers to the publication of a paper that overlaps substantially with one already published. Upon receipt, submitted manuscripts are screened for possible plagiarism or duplicate publication using Crossref Similarity Check. If a paper that might be regarded as duplicate or redundant had already been published in another journal or submitted for publication, the author should notify the fact in advance at the time of submission. Under these conditions, any such work should be referred to and referenced in the new paper. The new manuscript should be submitted together with copies of the duplicate or redundant material to the editorial committee. If redundant or duplicate publication is attempted or occurs without such notification, the submitted manuscript will be rejected immediately. If the editor was not aware of the violations and of the fact that the article had already been published, the editor will announce in the journal that the submitted manuscript had already been published in a duplicate or redundant manner, without seeking the author's explanation or approval.

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It is possible to republish manuscripts if the manuscripts satisfy the conditions for secondary publication of the ICMJE Recommendations, available from: https://www.icmje.org/ as follows:

(1) Certain types of articles, such as guidelines produced by governmental agencies and professional organizations, may need to reach the widest possible audience. In such instances, editors sometimes deliberately publish material that is also published in other journals with the agreement of the authors and the editors of those journals.

(2) Secondary publication for various other reasons, in the same or another language, especially in other countries, is justifiable and can be beneficial provid-

ed that the following conditions are met. The authors have received approval from the editors of both journals (the editor concerned with secondary publication must have a photocopy, reprint, or manuscript of the primary version). The priority of the primary publication is respected by a publication interval of at least one week (unless specifically negotiated otherwise by both editors).

(3) The paper for secondary publication is intended for a different group of readers; therefore, an abbreviated version could be sufficient. The secondary version faithfully reflects the data and interpretations of the primary version. The footnote on the title page of the secondary version informs readers, peers, and documenting agencies that the paper has been published in whole or in part and states the primary reference. A suitable footnote might read: "This article is based on a study first reported in the [title of a journal, with full reference]."

### Authorship

Authorship credit should be based on substantial contributions to all four categories established by the ICMJE: (1) substantial contributions to conception or design of the work, acquisition of data, and analysis and interpretation of data; (2) drafting the work or revising it critically for important intellectual content; (3) final approval of the version to be published; and (4) agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

- The contributions of all authors must be described. JMT has adopted the CRediT Taxonomy (https://credit.niso.org/) to describe each author's individual contributions to the work. The role of each author should be addressed on the title page.
- Correction of authorship: Requests for corrections in authorship (such as adding or removing authors, or rearranging the order of authors) after the initial manuscript submission and before publication should be explained in writing to the editor, in a letter or email signed by all authors. A completed copyright assignment form must be submitted by every author.
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- Contributors: Any researcher who does not meet all four ICMJE criteria for authorship discussed above but contributes substantively to the study in terms of idea development, manuscript writing, conducting research, data analysis, and financial support should have their contributions listed in the Acknowledgments section of the article.

### Process for Managing Research and Publication Misconduct

When the journal faces suspected cases of research and publication misconduct, such as redundant (duplicate) publication, plagiarism, fraudulent or fabricated data, changes in authorship, undisclosed conflict of interest, ethical problems with a submitted manuscript, appropriation by a reviewer of an author's idea or data, and complaints against editors, the resolution process will follow the flowcharts provided by COPE (http://publicationethics.org/resources/flowcharts). The discussion and decision on the suspected cases are carried out by the Editorial Board.

### Editorial Responsibilities

The Editorial Board will continuously work to monitor and safeguard publication ethics: guidelines for retracting articles; maintenance of the integrity of academic records; preclusion of business needs from compromising intellectual and ethical standards; publishing corrections, clarifications, retractions, and apologies when needed; and excluding plagiarized and fraudulent data. The editors maintain the following responsibilities: responsibility and

authority to reject and accept articles; avoid any conflict of interest with respect to articles they reject or accept; promote the publication of corrections or retractions when errors are found; and preserve the anonymity of reviewers.

### Artificial Intelligence (AI) Guideline

JMT adheres to the following guidelines specified by the ICMJE regarding the use of AI tools. These measures are essential to ensuring academic integrity and ethical standards.

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- Editor's authority: the editor may refuse to proceed with the review of a paper if inappropriate use of AI is detected. Additionally, this policy may evolve in response to advancements in technology and societal agreements.

## 4. EDITORIAL POLICY

### Copyright

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### Article Sharing (Author Self-Archiving) Policy

JMT is an open-access journal, and authors who submit manuscripts to JMT may share their research in several ways, including on preprint servers, social media platforms, at conferences, and in educational materials, in accordance with our open-access policy. Authors may deposit the accepted manuscript or published version in institutional repositories, provided that the original source (JMT, DOI, and publisher information) is clearly cited. All shared versions must include a link to the official publication on the JMT website. Commercial use of the published content is not permitted unless explicitly authorized by the publisher. Submitting the same manuscript to multiple

journals is strictly prohibited. This policy may be updated in response to changes in copyright law, licensing agreements, or publisher requirements.

### Registration of Clinical Trial Research

It is recommended that any research that deals with a clinical trial be registered with a clinical trial registration site, such as http://cris.nih.go.kr, or other primary national registry sites accredited by the World Health Organization (https://www.who.int/clinical-trials-registry-platform/network/primary-registries) or clinicaltrial.gov (http://clinicaltrials.gov/), a service of the United States National Institutes of Health.

### Data Sharing Policy

JMT encourages data sharing wherever possible unless this is prevented by ethical, privacy, or confidentiality matters. Authors wishing to do so may deposit their data in a publicly accessible repository and include a link to the DOI within the text of the manuscript.

- Clinical Trials: JMT accepts the ICMJE Recommendations for data sharing statement policy. Authors may refer to the editorial, "Data Sharing Statements for Clinical Trials: A Requirement of the International Committee of Medical Journal Editors," in the Journal of Korean Medical Science (https://dx.doi.org/10.3346/jkms.2017.32.7.1051).

### Archiving Policy

In accordance with the Korean Library Act, the full text of the JMT can be archived in the National Library of Korea. JMT provides electronic archiving and preservation of access to the journal content in the event the journal is no longer published, by archiving in the National Library of Korea (https://www.nl.go.kr/archive/search.do) and the National Library of Korea can permanently preserve submitted JMT papers.

### Preprint Policy

A preprint can be defined as a version of a scholarly paper that precedes formal peer review and publication in a peer-reviewed scholarly journal. JMT allows authors to submit preprints to the journal. It is not treated as duplicate submission or duplicate publication. JMT recommends that authors disclose the existence of a preprint with its DOI in the letter to the editor during the submission process. Otherwise, a plagiarism check program—Similarity Check (Crossref) or Copy Killer—may flag the results as containing excessive duplication. A preprint submission will be processed through the same peer-review process as a usual submission. If a preprint is accepted for publication, the authors are recommended to update the information on the preprint site with a link to the published article in JMT, including the DOI at JMT. It is strongly recommended that authors cite the article in JMT instead of the preprint in their next submission to journals.

## 5. MANUSCRIPT SUBMISSION AND PEER-REVIEW PROCESS

### Online Submission

All manuscripts should be submitted online via the journal's website (https://submit.e-jmt.org/) by the corresponding author. Once you have logged into your account, the online system will lead you through the submission process in a step-by-step manner. In case of any trouble, please contact the editorial office (Email: office@e-jmt.org).

### Screening after Submission

The screening process will be conducted after submission. If the manuscript does not fit the aims and scope of the Journal or does not adhere to the Instructions to authors, it may be returned to the author immediately after receipt and without a review. Before review, all submitted manuscripts are inspected using "Similarity Check powered by iThenticate (https://www.crossref.org/services/similarity-check/), a plagiarism-screening tool. If an excessively high similarity score is found, the Editorial Board will do a more profound content screening. The criterion for similarity rate for further screening is usually 25%; however, the excess amount of similarity in specific sentences may be also checked in every manuscript. The settings for Similarity Check screening are as follows: It excludes quotes, a bibliography, small matches of 6 words, small sources of 1%, and the Methods section.

### Peer-Review Process

All papers, including those invited by the Editor, are subject to peer review. Manuscripts will be peer-reviewed by two

accredited experts in the musculoskeletal trauma care with one additional review by a prominent member of our Editorial Board. The editor is responsible for the final decision whether the manuscript is accepted or rejected.

- The journal uses a single-blind peer-review process: the reviewers are aware of the identity of the authors, but the authors do not know the identity of the reviewer. During the peer-review process, reviewers may interact directly or exchange information (e.g., via submission systems or email) only with the editor, which is known as "independent review."
- JMT's average turnaround time from submission to decision is 6 weeks.
- Decision letter will be sent to corresponding author via registered email. Reviewers can request authors to revise the content. The corresponding author must indicate the modifications made in their item-by-item response to the reviewers' comments. Failure to resubmit the revised manuscript within 4 weeks of the editorial decision is regarded as a withdrawal.
- The editorial committee has the right to revise the manuscript without the authors' consent unless the revision substantially affects the original content.
- After review, the Editorial Board determines whether the manuscript will be accepted for publication. Once rejected, the manuscript does not undergo another round of review.
- All articles in JMT include the dates of submission, revision, acceptance, and publication on their article page. No information about the review process or editorial decision process is published on the article page.

### Submission by Editors

All manuscripts from editors, employees, or members of the Editorial Board are processed in the same way as other unsolicited manuscripts. During the review process, submitters will not engage in the selection of reviewers or the decision process. Editors will not handle their manuscripts even if the manuscripts are commissioned.

The conflict of interest declaration should be added as follows.

Conflicts of Interest: OOO has been an Editorial Board member of Journal of Musculoskeletal Trauma since OOO but has no role in the decision to publish this article. No other potential conflicts of interest relevant to this article were reported.

### Feedback after Publication

If the authors or readers find any errors or contents that should be revised, it can be requested from the Editorial Board. The Editorial Board may consider erratum, corrigendum, or a retraction. If there are any revisions to the article, there will be a CrossMark description to announce the final draft. If there is a reader's opinion on the published article with the form of Letter to the editor, it will be forwarded to the authors. The authors can reply to the reader's letter. Letter to the editor and the author's reply may also be published.

### Appeals of Decisions

Any appeal against an editorial decision must be made within 2 weeks of the date of the decision letter. Authors who wish to appeal a decision should contact the Editor-in-Chief, explaining in detail the reasons for the appeal. All appeals will be discussed with at least one other associate editor. If consensus cannot be reached thereby, an appeal will be discussed at a full editorial meeting. The process of handling complaints and appeals follows the guidelines of COPE. JMT does not consider second appeals.

## 6. MANUSCRIPT PREPARATION

Authors are required to submit their manuscripts after reading the following instructions. Any manuscript that does not conform to the following requirements will be deemed inappropriate and may be returned.

### General Requirements

- All manuscripts should be written in English.
- The manuscript must be written using Microsoft Word and saved as ".doc" or ".docx" format. The font size should be 11 points. The body text must be left-aligned, double-spaced, and presented in a single column. The left, right, and bottom margins must be 3 cm, but the top margin must be 3.5 cm.
- The page numbers should be placed in Arabic numerals at the center of the bottom margin, starting from the abstract page.
- Only standard abbreviations should be used. Abbrevi-

ations should be avoided in the title of the manuscript. Abbreviations should be spelled out when first used in the text and the use of abbreviations should be kept to a minimum.
- The names of manufacturers of equipment and non-generic drugs should be given.
- Authors should express all measurements in conventional units, using International System (SI) units.
- P-value from statistical testing should be expressed as capital P.

### Reporting Guidelines for Specific Study Designs

For the specific study design, it is recommended that authors follow the reporting guidelines, such as CONSORT (http://www.consort-statement.org) for randomized controlled trials, STROBE (http://www.strobe-statement.org) for observational studies, and PRISMA (http://www.prisma-statement.org) for systematic reviews and meta-analyses. A good source of reporting guidelines is the EQUATOR Network (https://www.equator-network.org/) and NLM (https://www.nlm.nih.gov/services/research_report_guide.html).

### Types of Manuscripts

- The manuscript types are divided into original articles, review articles, case reports, technical notes, letters to the editor, editorial, and other types.
- Original Articles: Original articles should be written in the following order: title page, abstract (within 300 words), keywords, main body (introduction, methods, results, discussion, and conclusions), acknowledgments (if applicable), references (up to 30), tables, figure legends, and figures.
- Review Articles: Review articles should focus on a specific topic. The format of a review article is flexible. Publication of these articles will be decided upon by the Editorial Board.
- Case Reports: Case reports should be a report on a single case or an analysis of a few cases to add to the clinical spectrum. Case reports should be written in the following order: title page, abstract (within 200 words), keywords, main body (introduction, case report, and discussion), acknowledgments (if applicable), references (up to 10), tables, figure legends, and figures.
- Technical Notes: Technical notes should be written in the following order: title page, abstract (within 200 words), keywords, main body (introduction, technique, and discussion), acknowledgments (if applicable), references (up to 20), tables (if applicable), figure legends, and figures. The total word count should not exceed 1,500 words.
- Letters to the Editor: The journal welcomes readers' comments on recently published articles or orthopedic topics of interest. Letters to the editor should not exceed 1,000 words, excluding references, tables, and figures. A maximum of 5 references and total 4 figures or tables are allowed.
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- Systematic Reviews and Meta-Analyses: Systematic reviews and meta-analyses should provide a comprehensive and structured overview of published material on a clearly defined subject. Authors must describe in detail how the evidence was identified, including the sources searched and the inclusion and exclusion criteria applied. Meta-analyses should quantitatively synthesize the results of two or more studies to address a specific research question or association. All systematic reviews and meta-analyses submitted to JMT must adhere to the PRISMA guidelines (http://www.prisma-statement.org).

**Table 1.** Recommended maximums for articles submitted to JMT[a]

| Type of article | Abstract (word) | Text (word)[b] | References | Tables & Figures |
|---|---|---|---|---|
| Original Article | Structured, 300 | NL | 30 | NL |
| Review | Unstructured, 300 | NL | NL | NL |
| Systematic Review | Structured, 300 | NL | NL | NL |
| Case Report | Unstructured, 200 | 1,500 | 10 | NL |
| Technical Note | Unstructured, 200 | 1,500 | 20 | NL |
| Letter to the Editor | - | 1,000 | 5 | 4 |
| Editorial | - | 1,000 | 10 | 4 |

[a]The requirements for the number of references, tables and figures and length of the main text can be consulted with the Editorial Office; [b]Excluding abstract, tables, figures, acknowledgments, and references.

### Format of Manuscript Title page

- The title page must include the title, the authors' names,

affiliations, and the corresponding author's name and contact information. The corresponding author's contact information must include their name and email. In addition, a running title must be provided, with a maximum of 50 characters, including spaces.

### Abstract and keywords

Each paper should begin with an abstract not exceeding 300 words (for original articles and reviews). The abstract for original articles should state the background, methods, results, and conclusions in each paragraph in a brief and coherent manner. Relevant numerical data should be included. Below the abstract, keywords should be provided (maximum of 5). Authors are encouraged to use the MeSH database to find Medical Subject Headings at http://www.nlm.nih.gov/mesh/meshhome.html. The structured abstract should be divided into the following sections.

- Background: The rationale, importance, or objectives of the study should be described briefly and concisely in one to two sentences. The objective should be consistent with that stated in the Introduction.
- Methods: The procedures conducted to achieve the study objective should be described in detail, together with relevant details concerning how data were obtained and analyzed and how research bias was adjusted.
- Results: The most important study results and analysis should be presented in a logical manner with specific experimental data.
- Conclusions: The conclusions drawn from the results should be described in one to two sentences and must align with the study objective.
- Level of evidence: Author should make the final determination of the study design and level of evidence based on the Centre for Evidence Based Medicine guidelines. Authors may refer to the definitions in the Level of Evidence table (https://www.cebm.ox.ac.uk/files/levels-of-evidence/cebm-levels-of-evidence-2-1.pdf).

### Main Body

- All articles using clinical samples or data and those involving animals must include information on the IRB/IACUC approval or waiver and informed consent. An example is shown below. "We conducted this study in compliance with the principles of the Declaration of Helsinki. The study protocol was reviewed and approved by the Institutional Review Board of OO (No. OO). Written informed consent was obtained / Informed consent was waived."
- Description of participants: Ensure the correct use of the terms "sex" (when reporting biological factors) and "gender" (identity, psychosocial, or cultural factors), and, unless inappropriate, report the sex and/or gender of study participants, the sex of animals or cells, and describe the methods used to determine sex and gender. If the study was done involving an exclusive population, for example, in only one sex, authors should justify why, except in obvious cases (e.g., ovarian cancer). Authors should define how they determined race or ethnicity and justify their relevance.
- Introduction: State the background or problem that led to the initiation of the study. Introduction is not a book review, rather it is best when the authors bring out controversies which create interest. Lead systematically to the hypothesis of the study, and finally, to a restatement of the study objective, which should match that in the Abstract. Do not include conclusions in the Introduction.
- Methods: Describe the study design (prospective or retrospective, inclusion and exclusion criteria, duration of the study) and the study population (demographics, length of follow-up). Explanations of the experimental methods should be concise, yet enable replication by a qualified investigator.
- Results: This section should include detailed reports on the data obtained during the study. All data in the text must be presented in a consistent manner throughout the manuscript. All issues which the authors brought up in the method section need to be in result section. Also, it is preferred that data be in figures or tables rather than a long list of numbers. Instead, numbers should be in tables or figures with key comments on the findings.
- Discussion: The first paragraph of the discussion should deal with the key point in this study. Do not start with an article review or general comment on the study topic. In the Discussion, data should be interpreted to demonstrate whether they affirm or refute the original hypothesis. Discuss elements related to the purpose of the study and present the rationales that support the conclusion drawn by referring to relevant literature. Discussion needs

some comparison of similar papers published previously, and discuss why your study is different or similar from those papers. Care should be taken to avoid information obtained from books, historical facts, and irrelevant information. A discussion of study weaknesses and limitations should be included, followed by a brief conclusion that clearly states the answer to the research question or hypothesis. Conclusions must be drawn only from the study results, and authors should verify that their data firmly support these conclusions. The conclusions in the text and those in the abstract must be consistent.

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- The contributions of all authors must be described using the CRediT (https://credit.niso.org/) taxonomy of author roles.
- References must be cited using numbers enclosed in square brackets, in the order of their first appearance in the text. When more than two quotations of the same authors are indicated in the main body, a comma must be placed between a discontinuous set of numbers, whereas a dash must be placed between the first and last numerals of a continuous set of numbers: "Kim et al. [2,8,9] insisted…" and "However, Park et al. [11-14] showed opposing research results."
- Figures and tables used in the main body must be indicated as "Fig." and "Table." For example, "Magnetic resonance imaging of the brain revealed… (Figs. 1-3).
- ORCID: We recommend that the open researcher and contributor ID (ORCID) of all authors be provided. To have an ORCID, authors should register in the ORCID website (http://orcid.org/).

## References

- References are recommended as 30 for original articles, 10 for case reports, and 20 for technical notes.
- All references must be cited in the text. The number assigned to the reference citation is according to the first appearance in the manuscript. References in tables or figures are also numbered according to the appearance order. Reference numbers in the text, tables, and figures should be enclosed in square brackets ([ ]).
- List all authors when there are six or fewer. When there are seven or more authors, list only the first three authors followed by "et al."
- Authors should be listed by surname followed by initials.
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- Overlapping page numbers (e.g., 2025-2026) should omit the repeated numerals (e.g., 2025-2026 should be written as 2025-6).
- References to unpublished material, such as personal communications and unpublished data, should be noted within the text and not cited in the References. Personal communications and unpublished data must include the individual's name, location, and date of communication.
- Examples of references are as follows: Journal article

① Journal

1. Song HK, Cho WT, Choi WS, Sakong SY, Im S. Acute compartment syndrome of thigh: ten-year experiences from a level I trauma center. J Musculoskelet Trauma 2024;37:171-4.
2. MacKechnie MC, Shearer DW, Verhofstad MH, et al. Establishing consensus on essential resources for musculoskeletal trauma care worldwide: a modified Delphi study. J Bone Joint Surg Am 2024;106:47-55.
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