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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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Complications of hand fractures: strategies for prevention and management

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Various complications can occur after hand fractures. Among them, joint stiffness and malunion are the most common and significant complications, which are often accompanied by tendon adhesions and joint contracture. Careful evaluations of injury characteristics, such as fracture patterns, alignment, and soft tissue injury, are the first step to select appropriate management strategies and prevent complications of hand fractures. Close observation of its clinical prognosis is also essential for early detection and preemptive management of complications. Management of complications includes immobilization, rehabilitation, and various surgical techniques such as tenolysis or capsular release for joint stiffness, corrective osteotomy for malunion, and revisional fixation with bone graft for nonunion. The authors discuss prevention, early recognition, and management strategies for complications of hand fractures in this review.

Keywords: Hand injuries; Complications; Malunited fractures; Complex regional pain syndrome

Review Article

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Introduction

Hand fractures, which include fractures of the metacarpal bones, proximal phalangeal bones, and distal phalangeal bones, are common fractures accounting for approximately 40% of upper extremity fractures [1]. The hand has a complex anatomical structure with many structures in a small space, making it prone to frequent complications regardless of the surgeon's ability or treatment method [2]. The complications that can occur in hand fractures include stiffness, malunion, deformity, nonunion, posttraumatic arthritis, infection, complex regional pain syndrome (CRPS; historically termed reflex sympathetic dystrophy), and nerve and vascular damage (Table 1) [2]. While the frequency of complications is higher in open fractures compared to closed fractures and in comminuted fractures compared to simple fractures, it is important to understand that complications can still occur in simple closed fractures [2,3].

Conservative treatment of hand fractures typically requires 3–4 weeks of splint immobilization, and there is the risk of inducing hand stiffness, malunion, and deformity during immobilization [2,4,5]. In contrast, surgical treatment allows for early finger movement after rigid fixation, which reduces the risk of hand stiffness, malunion, and deformity [2,6]. Surgical treatment is better for achieving good hand function but can also result in complications such as infection, hardware irritation, and nonunion [2,5,6]. The treatment of complications is challenging to manage, and complications

Table 1. Complications of hand fractures

Affected structure	Complication
Bone	Nonunion, malunion, delayed union, avascular necrosis, osteomyelitis, amputation
Soft tissue	Stiffness/motion loss, instability, laxity, poor durability, lack of coverage, contracture, flexion/extension loss
Tendon	Adhesions, lag, tightness
Nerve	Numbness, hypersensitivity, complex regional pain syndrome (reflex sympathetic dystrophy)
Vessel	Ischemia, congestion
Others	Vibration and temperature sensitivity, chondrolysis, acute pain, joint laxity

often cause unsatisfactory outcomes [2,6]. To achieve satisfactory treatment outcomes, it is important to recognize and prevent complications during treatment. The authors intended to discuss the treatment and prevention methods for the common complications, such as stiffness, malunion, deformity, nonunion, arthritis, infection, and chronic pain associated with hand fractures with a literature review in this article.

Ethics statement

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

Stiffness

Stiffness is the most common complication during the treatment of hand fractures and one of the most challenging complications to treat [2]. The risk of stiffness is higher in cases of severe comminuted fractures, open fractures, or crush injuries with extensive soft tissue damage around the fracture site (Fig. 1) [3]. Especially, proximal phalangeal fractures have a higher risk of stiffness compared to other hand fractures, so immobilization with a splint for more than 4 weeks can potentially cause stiffness [2]. Therefore, the key principle is to achieve sufficient stability to permit early protected active motion; rigid internal fixation is one way to accomplish this, but selected stable fracture patterns can also be managed nonoperatively with functional support while still allowing early mobilization [4,7-9]. In particular, uncomplicated fifth metacarpal neck fractures and selected metacarpal shaft fractures without rotational deformity or unacceptable shortening/angulation can often be treated functionally (e.g., buddy taping/soft wrap) with early protected mobilization, achieving outcomes comparable to more restrictive immobilization in appropriate patients [7-9]. A common mistake orthopedic surgeons make in treating hand fractures is unnecessarily prolonging rigid splint immobilization solely to observe radiographic callus formation. Phalangeal fractures typically heal within 4 weeks, but callus formation may not be visible on plain radiographs at that time [2]. Therefore, rather than continuing rigid immobilization, gentle active motion exercises of the joints can be carefully initiated if there is no focal tenderness or pain at the fracture site on physical examination at approximately 4 weeks [2]. If there are concerns about loss of reduction because radiographic healing appears insufficient, using a removable splint during active joint exercises and wearing the splint during other activities can be a practical alternative to prolonged rigid immobilization [2]. Early joint motion is essential, especially in hand crush injuries [4]. When a crush injury occurs to the hand, it damages all structures from the skin to the bone, causing severe swelling and stiffness of the soft tissues [3]. Therefore, early joint motion helps minimize swelling and soft tissue stiffness, but rigid fracture fixation is necessary to allow early motion [3].

Rigid internal fixation of fractures using plates allows early active joint motion, which can prevent hand stiffness, malunion, nonunion, and finger deformities [3]. However, there are disadvantages, such as the risk of tendon injury, nerve damage, and infection from surgical treatment [5]. Even with plate fixation, complications like finger stiffness or deformity can still occur if the fixation is not rigid enough to allow early joint motion or if the reduction is inadequate and finger alignment is incorrect [5,10].

Recently, intramedullary headless compression screw fixation has become popular as a minimally invasive surgical technique for extraarticular metacarpal and phalangeal fractures to provide stable fixation with minimal soft tissue dissection and extensor tendon irritation [11]. This technique may enable early active movement and reduce stiffness and adhesions [11]. In a recent meta-analysis,

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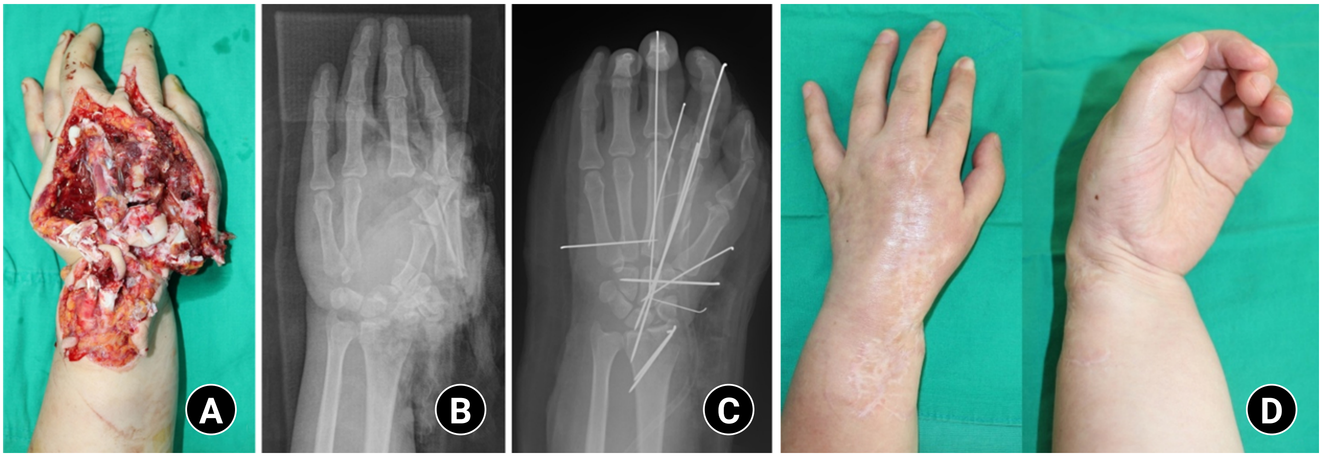

Fig. 1. (A) A case with multiple open hand fracture-dislocations and severe soft tissue injury. (B) Preoperative plain radiograph shows multiple hand and wrist fractures and dislocations. (C) A postoperative plain radiograph shows that temporary K-wire fixation was performed to maintain bony alignment and manage soft tissue injury. (D) The last follow-up photograph shows severe finger stiffness and permanent disability.

intramedullary screw fixation for metacarpal fractures had better patient-reported outcomes and a lower revisional surgery rate than K-wire fixation and plate fixation [12,13]. Nevertheless, the intramedullary screw fixation is only indicated in a particular fracture pattern without rotational instability and intraarticular involvement. Surgeons should know that this technique can also induce complications such as screw prominence/irritation, loss of reduction, and early arthrosis [11,14,15].

Percutaneous K-wire fixation is less invasive and a commonly performed simple technique to minimize new soft tissue damage. However, it has potential problems with infection and loss of fracture fixation that can lead to finger deformity, nonunion, malunion, stiffness, and decreased function [2,16]. Additionally, in elderly patients with poor bone quality, the fixation strength of K-wires may be weaker compared to younger patients [4,17]. For comminuted or unstable fractures, K-wires alone may not maintain fracture reduction [6]. K-wire fixation near joints can irritate soft tissues and prevent early joint motion [18]. Therefore, this technique is suitable for young adult patients with good bone quality [18]. However, percutaneous pinning can be performed even in elderly patients' fractures if it is stable without comminution and K-wire fixation alone is expected to provide sufficient stability for 4 weeks until union [16].

To minimize pin-related complications, postoperative care and rehabilitation should be individualized according to fracture stability and the configuration of the pins. While the K-wires are in place, early protected motion of nonimmobilized joints should be encouraged as pain and swelling permit, using a removable splint when needed to balance protection and mobilization [2]. Pin-site care protocols vary across institutions, and the choice of buried versus exposed wires should be individualized. In a recent systematic review and meta-analysis of hand and forearm fractures, buried K-wires were associated with a lower risk of pin-site infection compared with exposed wires, although the time to pin removal tended to be longer [13]. Meticulous aseptic insertion technique, standardized pin-site care with clear patient education regarding early signs of infection, and timely clinical follow-up remain key determinants of infection risk [15]. Radiographs are commonly obtained at 1–2-week intervals to confirm maintenance of reduction and to monitor healing progression. If there is no focal tenderness at the fracture site at approximately 4 weeks despite limited radiographic callus, the fracture may be considered clinically united [16]. In that setting, the K-wires can be removed, and active finger exercises can be advanced to prevent joint stiffness and minimize ongoing pin-related problems [16].

Treatment of finger stiffness is challenging. The first step in the treatment of finger stiffness is identifying the cause of the stiffness; physical examination is very important for determining the cause [2,17,19]. On physical examination, if there is stiffness with both active and passive motion of the finger, it indicates joint capsule contracture [2,17,19]. If there is stiffness only with active motion but not passive motion, it indicates adhesion of tendons to the fracture site soft tissues, joint capsule, bone, or hardware [2]. Initial treatment of stiffness is aggressive finger exercise rehabilitation to maximize range of motion, and many patients recover sufficient motion for activities of daily living [2]. However, if more than 3 months have passed since the fracture, recovery of joint motion cannot be expected with rehabilitation alone, and surgical treatment is necessary [20]. Before surgical treatment for joint stiffness, plain radiographs should confirm that the fracture has healed with sufficient strength and intensive joint rehabilitation should be performed postoperatively [20].

The surgical technique for finger joint contracture release varies depending on the location and severity of the stiffness [3,17]. For example, in cases of flexion contracture of the metacarpophalangeal joint (MCP), surgical procedures are sequentially performed, including skin incision, adhesiolysis of finger flexor tendons, and release of the volar plate and volar portions of the collateral ligaments [3,17]. The same technique is used for flexion contracture of the proximal interphalangeal joint (PIP) for MCP flexion contracture. Still, there are differences in the specific techniques for extension contracture of the MCP and PIP joints (Table 2) [2,6]. Previous reports have stated that surgical treatment of finger stiffness can recover up to 70° of joint range of motion [2,21]. However, complete recovery is not possible, so many cases are still unsatisfactory even after surgery [2,21]. Therefore, prevention of finger stiffness through early joint motion can be considered the best treatment.

Malunion

Malunion is a united fracture that has healed in an abnormal alignment [22]. All malunions always need to be treated, but treatment is necessary if this abnormal alignment causes impaired hand function [23]. Finger malunions can be classified into intraarticular and extraarticular malunions [24]. Intraarticular malunions greater than 1 mm can lead to posttraumatic arthritis [22]. Furthermore, severe malunions can cause finger deformities, resulting in significant functional impairment [2]. Although articular cartilage damage at the time of injury cannot be healed, joint surface incongruence that is severe enough to cause finger deformity or posttraumatic arthritis should be surgically corrected [2]. Surgical correction should be performed before the complete fracture union because correction becomes much more difficult after the union. Treatment options for intraarticular malunions depend on the degree of finger deformity, type of injured joint, and presence of arthropathy [2]. Surgical methods include corrective osteotomy, arthroplasty, and arthrodesis [4,24]. If intraarticular fractures have completely malunited, extraarticular corrective osteotomy can be used to realign the finger because direct correction is technically difficult [4,24].

Extraarticular malunion is the abnormal alignment of healed fractures outside the joint [4,24]. While extraarticular malunions are generally easier to treat than intraarticular malunions, corrective osteotomy should be performed if finger deformity is severe enough to cause impairment of normal joint function [25]. According to Freeland et al. [26] corrective osteotomy is commonly indicated for extraarticular malunions in the following cases:

(1) Angular deformity >15° in the middle and proximal

Table 2. Recommended surgical procedures to release hand joint stiffness

Affected joint and conditions	Sequence of procedures
MCP stiff in extension	Release (1) skin and extensor from capsule, (2) dorsal capsule, (3) articular surface and volar pouch, (4) dorsal half of collateral ligaments
MCP stiff in flexion	Release (1) skin, (2) adhesions of long flexors, (3) volar plate, (4) volar half of collateral ligaments
PIP stiff in extension	Release (1) skin, (2) extensor from capsule (preserve central slip), (3) dorsal capsule, (4) dorsal third to half of collateral ligaments
PIP stiff in flexion	Release (1) skin, (2) retinacular ligaments, (3) adhesions of long flexors, (4) volar half of collateral ligaments, (5) volar plate

MCP, metacarpophalangeal joint; PIP, proximal interphalangeal joint.

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phalanges; (2) articular incongruity; (3) angular deformity >10° in the index and middle metacarpal bones; (4) angular deformity >20° in the ring finger metacarpal bone; (5) angular deformity >30° in the little finger metacarpal bone; (6) rotational malunion >10° in the metacarpal bone (Fig. 2).

The index and middle fingers have limited carpometacarpal joint (CMC) motion compared to other digits, so they have a smaller acceptable range for angular deformity and may require surgical correction even for minor angulation. In contrast, the ring and little finger have greater mobility at the fourth and fifth CMC and can tolerate up to 30° of metacarpal angulation without functional impairment [26]. For shortened malunions of >2 mm in metacarpal bone, each 2 mm of shortening causes 7° of extension lag and decreased flexion strength at the MCP [26]. Therefore, lengthening osteotomy is needed. Angular malunion of the proximal phalanx has an effect similar to shortening malunion [27]. Angular deformity >15° causes functional impairment, and shortening >1 mm of the proximal phalanx leads to extension lag at the PIP. In those cases, corrective osteotomy should be performed [27].

Metacarpal malunion

Metacarpal malunions typically present with a dorsal angulation due to the deforming forces of intrinsic and extrinsic flexor muscles [25,28]. Rotational forces may also be present, which can be evaluated with the fingers in a flexed position [4,25]. Shortening can occur in oblique and comminuted metacarpal fractures [4,25]. While up to 6 mm of shortening can be tolerated due to compensatory hyperextension of the MCP joint, each additional 2 mm of shortening results in 7° of extension lag [4,6,25]. Shortening also reduces strength, with 2 mm of shortening causing an 8% loss of strength, and 10 mm of shortening resulting in a 45% reduction in grip strength [2]. While exact guidelines vary, angular deformities of up to 10° in the index and middle fingers and up to 20° and 30° in the ring and little fingers can be tolerated, respectively [2].

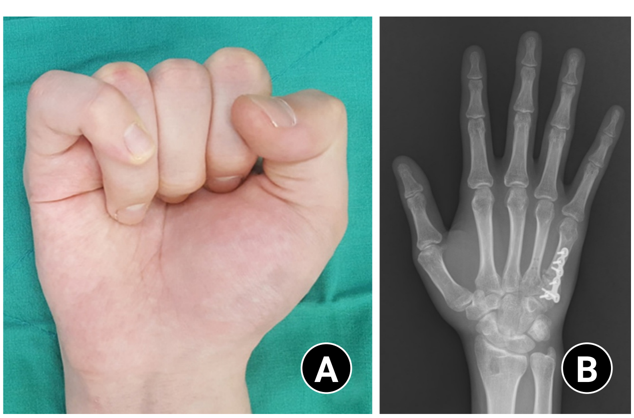

Fig. 2. (A) A case with rotational malunion of the fifth metacarpal bone that induces finger scissoring and disability. (B) Finger scissoring can be corrected by derotational osteotomy.

Osteotomies can be performed at the fracture site or at a distance from the fracture [2]. The advantages of performing the osteotomy at the fracture site include restoring normal anatomy without creating a zigzag deformity, allowing access to soft tissues for tenolysis and capsulectomy, and correcting multiple deformities [25,28]. Therefore, osteotomy should be performed at the fracture site whenever possible [25,28]. Both open and closed wedge osteotomies can be performed for angular deformities [27]. Closed wedge osteotomies are easier and more reliable, but shorten the metacarpal bone [27]. Open wedge osteotomies can be used when shortening also needs correction, and cancellous bone grafting alone is sufficient if fixation is rigid [27]. K-wires can also be used for stabilization, but plates and screws are preferred to allow early motion in open wedge osteotomies [27].

Rotational malunions can cause finger overlap and are less tolerated as adjacent joints cannot compensate for the deformity [25]. As little as 5° of rotational malunion can cause 1.5cm of finger overlap [2]. Rotational osteotomies can be performed at the fracture site or at the proximal base as described by Weckesser [29], allowing correction of up to 18° for the index, middle, and ring metacarpal bones and up to 30° for the little finger metacarpal bone. In cases with significant angular deformity, the osteotomy at the fracture site is a better surgical technique for simultaneously correcting both rotational and angular deformities [25]. Another excellent option for rotational deformities is the proximal step-cut osteotomy first described by Manktelow et al. [30], which allows for greater bone contact area and fixation with lag screws without the use of bulky plates. Fixation can be performed with K-wires or plates and screws. Many studies have been published on the results with high healing rates, deformity correction, and patient satisfaction of correction of rotational malunions with the above techniques.

Phalangeal malunion

Phalangeal malunions can also present with coronal and sagittal plane angular, rotational, and shortening deformity, similar to metacarpal malunions. Proximal phalangeal malunions characteristically show a volar angulation due to the flexion of the proximal fragment by the interossei and extension of the distal fragment by the central slip of the extensor tendon [22,23,31]. Biomechanically, the dorsal surface of the bone becomes relatively shorter compared to the extensor tendon length when the volar angulation exceeds 15° [22]. That results in about 12° of extension lag for every 1 mm shortening. When the angle exceeds 25°, both flexion and extension are impaired [22]. The tendency for extension lag and stiffness in the PIP joint can quickly lead to fixed flexion contractures [22].

Middle phalangeal malunions present with a dorsal angulation if the fracture is proximal to the flexor digitorum superficialis tendon (FDS) insertion and a volar angulation if distal to the FDS insertion [27]. Volar angulation is more common and can significantly affect flexor tendon biomechanics [27]. Phalangeal osteotomy at the fracture site is better than at other phalangeal sites or the metacarpal level [22]. This allows simultaneous tenolysis and fixing of the other causes of deformity. However, performing osteotomy at the base of the proximal phalanx rather than near the PIP joint may be considered to reduce the risk of contracture [22]. A closed wedge osteotomy using the dorsal periosteum as a hinge is a good option for volar malunions [22]. This maintains bone length relative to the extensor tendon and allows good apposition of bone ends during healing [2]. A lateral plate can then be applied apart from the tendons to reduce adhesions and allow early motion. For severely angulated malunions where the bone is significantly shortened relative to the tendons, a dorsal opening wedge osteotomy with a dorsal plate fixation should be performed [31]. This theoretically restores the original bone length but causes a higher risk of adhesion formation and stiffness [31]. Coronal plane malunions are often due to bone loss on the fracture site [31]. Good results have been shown with an opening wedge osteotomy, bone grafting, and lateral plate fixation while preserving the cortex on the apex side. Rotational deformities may be combined with angular deformities and shortening and corrected simultaneously [2]. Buchler et al. [32] reported 100% union rates and deformity correction of phalangeal malunions, but 50% of cases required simultaneous tenolysis and/or capsulectomy due to the high incidence of tendon adhesions and joint contractures. Trumble and Gilbert [33] recommended in situ osteotomy of the phalanx at the fracture site rather than the metacarpal bone because simultaneous tenolysis and capsulotomy could be performed in most cases. All of their patients healed and had complete correction of deformity, with improvements of 15° in PIP joint motion and 10° in distal interphalangeal joint (DIP) motion [2]. Therefore, treatment of phalangeal malunions is more challenging than metacarpal malunions due to the surrounding intrinsic apparatus and extrinsic tendons, the tendency for tendon adhesions, and the development of PIP joint contractures. Surgical treatment can significantly improve hand function and patient satisfaction [2].

Nonunion

Nonunion is a relatively rare complication in hand fractures due to the rich blood supply, but it can occur commonly in complex injuries such as open fractures with associated nerve, vascular, and tendon injuries, or crush injuries [28]. They are also surgical complications resulting from the disruption of microvascular blood supply around the bone during open reduction or inadequate fracture reduction with a wide fracture gap [23]. Most nonunions in hand fractures are atrophic nonunions, often associated with bone loss or infection [28]. When atrophic nonunion occurs, the nonunited bone should be debrided and treated with rigid internal fixation and autologous bone grafting harvested from sites like the distal radius or olecranon [28]. Hypertrophic nonunion after hand fractures is rare but can be easily treated with more rigid internal fixation alone [28].

Diagnosing nonunion in hand fractures can be challenging, as radiolucent lines may be visible on plain radiographs for up to a year after fracture [2]. However, if there are no clinical symptoms such as pain at the fracture site, the fracture can be considered united. Therefore, other factors such as pain, instability, deformity, and fixation failure should be considered when diagnosing fracture nonunion along with plain radiographs [2]. To avoid the risk of finger joint stiffness, fracture sites should not be immobilized for more than 6 weeks, even if the union is delayed [6]. If both

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nonunion and joint stiffness exist, the joint should be released simultaneously with surgical treatment of the nonunion [6].

In many cases of nonunion, salvage procedures such as arthrodesis or amputation may be necessary to treat associated injuries [23]. Conservative treatments like bone stimulators have not been proven effective to date [23]. Nonunion of the distal phalangeal shaft is relatively common and can be treated with compression screws alone or with bone grafting if the fracture is atrophic [34]. Autologous grafting is the standard technique for nonunion treatment, and cancellous autografts are generally sufficient to stimulate healing [34]. Structural autografts can be used for significant bone defects in the load-sharing portion [34]. Cancellous autograft chips can be compressed in a syringe to create a semistructural bone peg, which may be suitable for most hand fractures [2]. Technically, all atrophic and nonviable bone should be debrided until bone bleeding is visible [23]. Implants used for internal fixation in the nonunion should be slightly larger than those typically used for acute fractures to provide additional mechanical stability [23]. Few studies have reported on outcomes after surgical management of nonunions with internal fixation and bone grafting, and the results are not satisfactory [20,23,27,28,35-37]. Harness et al. [38] reported that, among 25 patients with nonunion (including 15 complex hand injuries), few fingers achieved good function; however, plate-and-screw fixation provided better stability than K-wire fixation. The authors' experience was similar (Fig. 3).

Due to the limited success rate of nonunion reconstruction through bone grafting and revisional internal fixation, arthrodesis and amputation play important roles in the surgical treatment of nonunions [27]. Arthrodesis is suitable for intraarticular and periarticular nonunions with severe joint stiffness [27]. Amputation is indicated for nonunion with significant bone loss, chronic infection, permanent sensory loss, and poor soft tissue coverage [27]. Stiff fingers often inhibit hand function, and the nonunited stiff finger also requires protection and causes stiffness in adjacent fingers [17]. Therefore, amputation is a good solution for these patients and almost always improves their function [17,27].

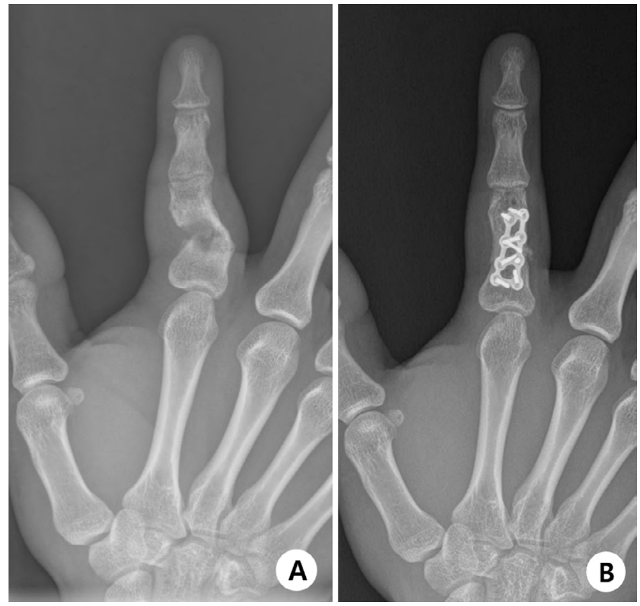

Fig. 3. (A) A case with atrophic nonunion and consequent reduction loss. (B) Atrophic nonunion can be treated surgically by stable fixation and autogenous cancellous bone graft.

Arthritis

Posttraumatic arthritis can result from intraarticular malunion or cartilage damage [27]. While cartilage damage may be irreversible, joint incongruity can be surgically corrected and is much easier to correct at the acute state [27]. Treating established intraarticular malunions can be very challenging. Treatment options depend on the patient, deformity, involved joint, and presence of arthropathy, and may include osteotomy, various types of arthroplasty, and arthrodesis [2,6].

There are two general techniques to correct intraarticular malunions: For malunions less than 8–10 weeks old where the old fracture line is still definable, an osteotomy through the fracture can reverse the deformity and improve articular congruence [27]. However, this requires manipulating and fixing small, unstable articular fragments, which theoretically risks biological breakdown and fixation failure [31,38]. For chronic malunions where the fracture line is no longer visible, special osteotomy techniques are needed to reduce the articular surface [38]. Teoh et al. [39] described a technique of wedge osteotomy in the intercondylar region to create a larger condylar fragment. This allows easier correction of articular malunion and fixation of a larger fragment [39]. It theoretically reduces risks of fixation failure, nonunion, and osteonecrosis [39]. A supracondylar closing wedge osteotomy just proximal to the collateral ligament insertion has also been described with good results [2,31,40]. For the most severe deformities with arthropathy, arthrodesis and arthroplasty are excellent options [23]. Bony mallet injuries can cause intraarticular malunions of the DIP joint [41]. The main concern with these injuries is the extension lag of the DIP joint and consequent hyperextension of the PIP joint, resulting in a swan neck deformity [41]. Incongruity can also induce DIP arthropathy. In those cases, arthrodesis in 5°–10° of flexion is most optimal in hand function [41].

Malunions around the PIP can also be combined with stiffness and angular and rotational deformities [25,31]. Treatment options are extraarticular and intraarticular osteotomies, depending on the deformity, as described above. For dorsal PIP fracture-dislocations with volar articular surface loss of the middle phalanx, volar plate arthroplasty or hemihamate arthroplasty can be used [25,31]. While volar plate arthroplasty can have flexion contracture and recurrent instability, hemihamate arthroplasty is effective for up to 50% articular surface loss [25,31]. If the deformity cannot be reconstructed or arthropathy already exists around the index PIP, arthrodesis is the best treatment option to provide a stable base for pinch, while the remaining fingers can be treated with arthroplasty to preserve motion [23,42].

Malunions around the MCP occur less frequently but can be challenging to treat. Again, treatment options include intraarticular and extraarticular osteotomies [40]. Arthrodesis and arthroplasty are suitable for severe, uncorrectable deformities with arthropathy [40]. Arthrodesis of the index MCP may be a desirable option to provide stability of the MCP during pinch, like in the PIP, but the other MCP should be treated with arthroplasty [22].

Infection

The infection rate in hand fractures is related to the severity of soft tissue damage and wound contamination [27,35]. Necrosis of surrounding soft tissues and periosteal stripping creates an environment vulnerable to infection [27]. In open hand fractures, osteomyelitis can occur up to 11% after surgical treatment [2,43]. Some reports indicate that treatment of osteomyelitis in hand fractures is challenging, and the amputation rate is up to 40% [2,43]. The definitive diagnosis of osteomyelitis is possible only by bone culture [2,43]. Clinically, patients present with swelling, erythema, tenderness, limited motion, and sometimes draining sinuses [20,44,45]. Fever is usually absent, but inflammatory markers like C-reactive protein are elevated. White blood cell counts may be normal or elevated. X-rays may show sequestrum and involucrum in chronic cases [19,34].

Acute osteomyelitis without abscess formation can be managed by intravenous antibiotics with monitoring clinical status and inflammatory markers, followed by a short course of oral antibiotics once inflammatory markers normalize [19,34]. Surgical treatment is necessary for chronic or acute osteomyelitis with an abscess. The surgical goals are to remove all infected and nonviable tissue, including bone, adequately stabilize the fracture, and provide sufficient soft tissue coverage [32,37]. Loosened hardware should be removed, and fractures should be stabilized with external fixation [6,20]. Also, hardware should be removed if the fracture has united. However, if the fracture has not yet united, hardware should not be removed until union with chronic suppressive antibiotics [6,20]. Dead space can be managed with antibiotic-impregnated cement spacers and external fixation. Flap coverage is helpful for soft tissue defects. Antibiotic-impregnated cement spacers can be used with external fixation to maintain length and alignment. Final reconstruction can be performed after the infection is completely cured [3].

Chronic pain

The exact incidence of CRPS after hand fractures is unknown, but CRPS is recognized as a not-uncommon complication following upper extremity injuries [46]. It has been reported after distal radius fractures and fasciectomy for Dupuytren disease [28,46-48]. While it can also occur after hand fractures, there is limited information in the current literature regarding CRPS specifically following hand fractures [28]. Clinically, CRPS presents with continuing pain disproportionate to the inciting event, often accompanied by sensory disturbance (allodynia/hyperalgesia), autonomic changes (temperature or color asymmetry), edema/sudomotor abnormalities, and motor/trophic changes that may ultimately impair function [27,28,47,48].

CRPS is primarily a clinical diagnosis without a defini-

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tive confirmatory test. Current recommendations support the use of the Budapest clinical criteria, which require disproportionate continuing pain, symptoms in at least three of four categories (sensory, vasomotor, sudomotor/edema, motor/trophic), signs in at least two categories on examination, and the exclusion of alternative diagnoses that better explain the presentation [49,50]. In patients with disproportionate pain after treatment of a hand fracture, clinicians should also evaluate for other causes such as infection, malunion/nonunion, tendon adhesions, and discrete peripheral nerve pathology, as these may mimic or coexist with CRPS [27,47].

Cold hypersensitivity has been widely reported in the literature as a symptom of CRPS, but it remains poorly understood and challenging to treat [27,28,47,48]. CRPS can manifest as chronic pain, nonunion, stiffness, edema, atrophy, cold hypersensitivity, and radiographic osteopenia of the hand [27,28,47,48]. CRPS may also occur due to sympathetic hyperactivity without specific nerve damage or surgical nerve injury [46]. Therefore, when symptoms follow a specific nerve distribution, diagnostic injections with local anesthetics may help identify neuromas or nerve compression [47]. Ancillary tests may be used selectively to exclude alternative diagnoses or to support clinical suspicion; however, they should not delay management. In particular, three-phase bone scintigraphy has limited diagnostic utility for CRPS of the hand and may postpone timely rehabilitation or necessary surgical decision-making [49,51]. Sympathetic nerve blocks are not diagnostic, but may be considered as part of a multidisciplinary treatment strategy in selected patients when sympathetic features are prominent, to facilitate participation in rehabilitation [49,51].

Early recognition is the most important for the good prognosis of CRPS [52]. The management goal of CRPS is functional restoration [27,47,49]. Initial treatment includes antidepressants, anticonvulsants, calcium channel blockers, and adrenergic agents, along with hand therapy to prevent stiffness [27,47]. Opioids can also be used. Nevertheless, continuous rehabilitation is essential to maintain hand function, patients may not be cooperative with hand therapy due to severe pain [27,47]. Warm baths and transcutaneous electrical nerve stimulation devices may be helpful with pain control [52]. Adjunctive noninvasive neurocognitive treatment, such as graded motor imagery and mirror therapy, may also facilitate pain reduction and functional recovery [49].

Surgical intervention should not be considered for CRPS itself. However, specific procedures, such as neurolysis, nerve decompression, or neuroma excision, may be appropriate only for specific peripheral nerve pathology [47,49]. For patients with refractory systemic sympathetic hyperactivity, sympathectomy may be helpful in certain cases [47].

Conclusions

Complications can occur in hand fractures regardless of the treatment method and severity of injury. If complications occur, their treatment is challenging, and the treatment outcomes also can be poor. Since prevention of complications is the best way to achieve good treatment outcomes, orthopedic surgeons should possess profound knowledge and experience regarding the causes of complications and pay attention to avoiding complications in hand fractures.

Article Information

Author contributions

All the work was done by Jong Woo Kang.

Conflicts of interest

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

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Supplementary materials

None.

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Epidemiological changes and surgical trends of distal radius fractures in adults over 50 years during the COVID-19 pandemic in Korea: a nationwide repeated cross-sectional study

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Background: The COVID-19 pandemic is likely to have affected bone health in older adults in Korea. This study aimed to analyze changes in the epidemiology and management of distal radius fractures (DRFs) in older adults before and during the COVID-19 pandemic.

Methods: Patients with DRF aged over 50 years in 2017, 2018, 2020, and 2021 were included in this study. Patients were classified into a group with DRF occurring between 2017 and 2018 (before COVID-19) and a group with DRF occurring between 2020 and 2021 (during COVID-19). We calculated the incidence rates of DRF and compared them between the two groups. We also analyzed and compared demographic data (age, sex, income, residence) and the operation rate for DRF between the two groups. Patient selection and treatment were based on International Classification of Diseases, 10th revision codes.

Results: A total of 140,634 patients with DRF (before COVID-19, 69,794; during COVID-19, 70,840) were included. The incidence of DRF before COVID-19 (184.4/100,000 person-years) was higher than during COVID-19 (169.8/100,000 person-years). The operation rate was higher during COVID-19 (86.9%) than before COVID-19 (83.3%).

Conclusions: During the COVID-19 pandemic, the incidence of DRF decreased in South Korea. However, the rate of surgical treatment increased and exceeded the global surgical rate.

Level of evidence: III.

Keywords: COVID-19; Radius fractures; Wrist fractures; Disease management

Original Article

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Introduction

Background

Distal radius fractures (DRFs) account for approximately 16% of all fractures treated by orthopedic surgeons [1,2]. In contrast to high-energy-induced DRFs, which primarily occur in a relatively young population (ages, 5 to 24 years) and predominantly among males, DRFs in the older adults population—predominantly female—often result from low-energy trauma, such as simple falls during daily activities. DRFs in older adults represent a hallmark of fragility fractures in the upper extremity, alongside osteoporotic fractures of the spine and hip. Although DRFs can occur in younger individuals, they are more commonly seen in men over 60 years of age and women after menopause, typically in their 50s [3].

As life expectancy increases in Korea, DRF in older adults has also been increasing and medical costs rose accordingly [4,5]. Before the COVID-19 pandemic, advancements in medical science and the increasing prevalence of physically healthy older adults contributed to a higher proportion of active treatments, including surgical interventions. This shift was further driven by the growing number of patients seeking rapid recovery following DRFs.

Since the outbreak of COVID-19 in late 2019, the global community has faced unprecedented challenges. The pandemic's rapid spread, coupled with high mortality rates, has significantly increased medical demand. Countries worldwide implemented varying strategies to combat COVID-19, with particular attention to the older adults, who are at heightened risk for severe illness and death. These health risks necessitated greater care and precautionary measures for the older adult populations, including wearing masks, social distancing, and avoiding public places. Consequently, many older adults experienced increased feelings of isolation and loneliness, exacerbated by the closure of public spaces like restaurants, parks, and gyms. These changes forced seniors to adapt to alternative methods for staying active and maintaining their health.

This restricted environment is likely to have affected bone health in the older adult population in Korea, and it is highly likely to have changed the pattern of osteoporotic fractures during this COVID-19 period. Even if an actual osteoporotic fracture occurs, appropriate treatment might not have been provided because of limited medical capacity during the COVID-19 pandemic, and changes in complications and mortality rates can also be expected.

Objectives

Based on these changes, we hypothesized that the incidence of DRFs would decline due to reduced outdoor activity, and that surgical treatment rates would also decrease because of limited access to operative care. Therefore, this study aimed to evaluate nationwide changes in the incidence and management patterns of DRFs before and during the COVID-19 pandemic in Korea.

Methods

Ethics statement

This study was conducted with approval from the Institutional Review Board (IRB) of National Health Insurance Service Ilsan Hospital (IRB No. NHIMC-2023-03-062), which waived the requirement for informed consent as the data were analyzed anonymously.

Study design

It is a repeated cross-sectional study based on data from the National Health Insurance Service (NHIS) of Korea to compare the incidence and operation of DRF before and during COVID-19 pandemic.

Setting

NHIS qualification data were accessed and the data for target population during the periods 2017–2018 and 2020–2021 were retrieved.

Participants

Patient selection for each disease and treatment was based on ICD-10 codes registered with the NHIS. Study participants were identified using NHIS qualification data and included patients aged over 50 years who were diagnosed with DRFs during the periods 2017–2018 and 2020–2021. The ICD-10 codes for DRFs (S52.5 and S52.6) were used for this purpose. To ensure reliable data collection and include only newly diagnosed DRFs within the study periods, a washout period was applied in 2016 and 2019, during which patients identified were excluded from the analysis.

After the initial screening and identification of all patients for the relevant study periods, operation prescription codes (N0603, N0607, N0613, N0617, N0983, N0993, N0994, N0996, N0998, N1601, N1603, N1611, and N1613) were used to identify treatment procedures following the diagnosis. These codes are detailed in Supplement 1. The flowchart illustrating patient selection and categorization is provided in Fig. 1.

Variables

The primary exposure was calendar period, categorized as pre-COVID-19 (2017–2018) and during COVID-19 (2020–2021). Primary outcome variables for comparison were incidence of DRF. The secondary outcomes included

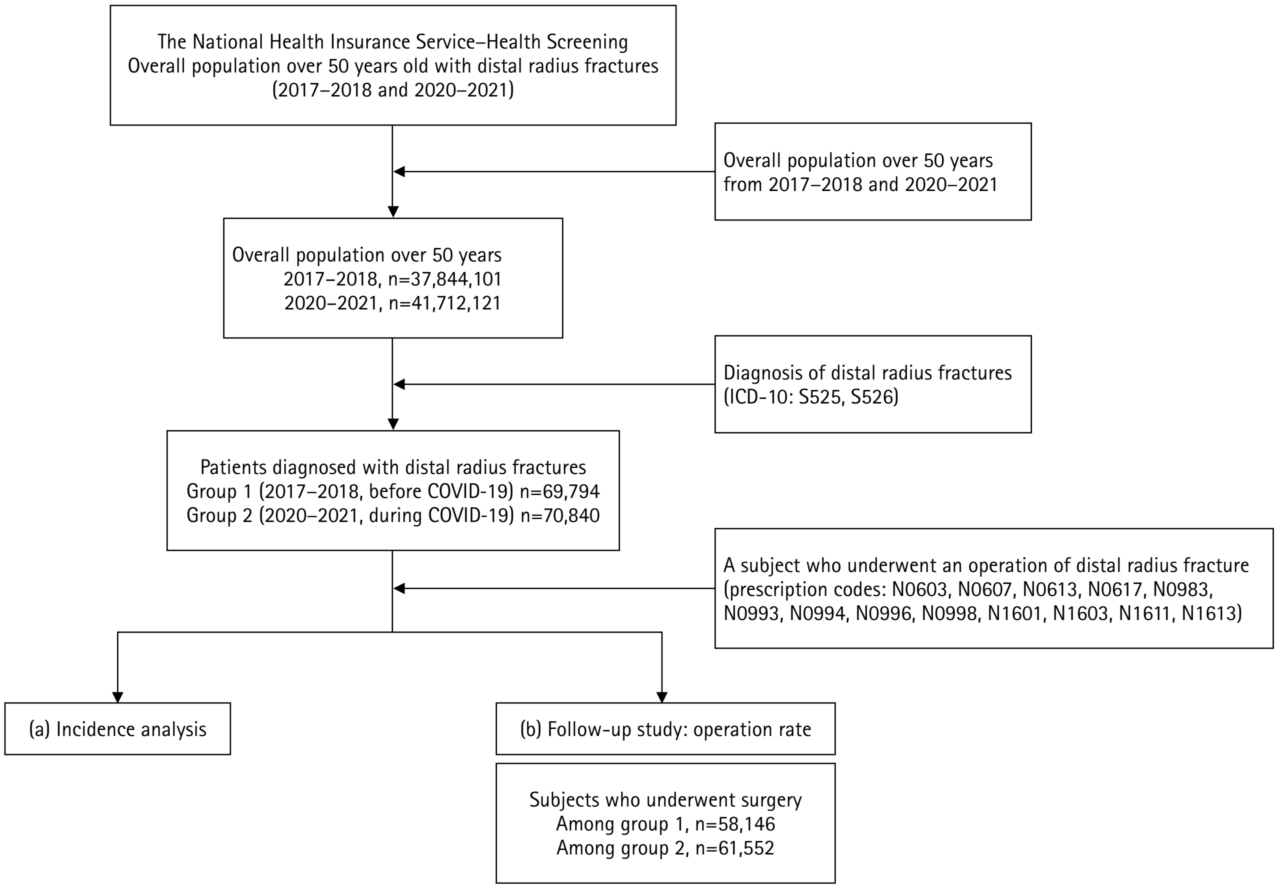

Fig. 1. Schematic diagram depicting the study population.

operation rates, surgical technique category, and all-cause mortality within 1 year of the index date. Patient-level covariates included sex, age, income, residence, mortality rate within one year, and the Charlson Comorbidity Index (CCI) score at index date.

Data sources

The study population was drawn from the NHIS, the single largest public insurer in Korea, providing health coverage for all citizens residing in South Korea [6]. The NHIS maintains comprehensive datasets encompassing 99% of claims data from healthcare providers. These datasets include information on both inpatients and outpatients, covering demographics, diagnoses, and prescriptions. The data fields include sex, age, diagnosis codes based on the International Classification of Diseases (ICD-10) and Korean Classification of Diseases (KCD), as well as treatments covered by the NHIS.

Incidence analysis

All patients with DRFs from 2017 to 2018 were designated as the reference group 1 (before COVID-19), while patients from 2020 to 2021 were categorized as the comparison group 2 (during COVID-19). The incidence rate of DRF was calculated for each group by dividing the number of cases by the total time at risk for all individuals to develop the condition [7]. More specifically, we estimated incidence rates by dividing the total number of incident DRF cases in each 2-year period by the sum of the mid-year populations aged 50 years and older in the corresponding two calendar years, which approximates the total person-years at risk. The results are expressed per 100,000 person-years.

Comparison between before and during COVID-19 groups

Operation rate and type of surgery

We analyzed the number of subjects who underwent operative treatment following a diagnosis of DRF. Operative management was identified using the prescription origin

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codes of NHIS (Supplement 1). Additionally, the type of surgery—including open reduction and internal fixation (ORIF), closed reduction and pinning, and external fixation—was categorized based on the corresponding NHIS prescription codes.

Other demographics

We measured and compared gender, age, income, residence, mortality rate within one year, and the CCI score between the two groups [8]. Income levels were categorized into five groups at 20% intervals, with level 1 representing the lowest income and level 5 the highest. Residential areas were classified into metropolitan and nonmetropolitan regions. The CCI score was calculated to predict mortality based on concurrent conditions such as heart disease, AIDS, or cancer, encompassing a total of 17 categories. A score of zero indicates no comorbidities, while higher scores correspond to an increased predicted mortality rate.

Bias

Potential biases include misclassification, as DRFs and surgeries were identified using administrative codes rather than radiographic confirmation. Duplicate counting may occur due to repeated claims; we minimized this by applying washout periods and an episode-based counting rule, which considers only the first qualifying claim per individual within each period. Ascertainment bias is possible during the COVID-19 pandemic if healthcare-seeking behavior or access to care changed, potentially leading to under-recording of fractures.

Study size

A formal sample size calculation was not performed because this was a population-based study using nationwide claims data. We included all eligible NHIS beneficiaries aged ≥50 years within the prespecified calendar periods and captured all incident DRF cases meeting the operational definition.

Statistical methods

For continuous data, the mean, standard deviation, minimum, and maximum values were presented, while categorical data were summarized as frequency and percentage. Pearson chi-squared test was employed to determine statistical significance between the two groups. All statistical analyses were conducted using SAS ver. 9.4 (SAS Institute) and R ver. 4.4.2 (R Foundation for Statistical Computing).

Results

Participants

The details of total population and patients with DRF were summarized in Table 1.

Incidence analysis

The total population of the pre-COVID-19 group (group 1, 2017–2018) aged over 50 was 37,844,101. Among them, 69,794 subjects were diagnosed with DRFs. Similarly, the total population of the during-COVID-19 group (group 2, 2020–2021) was 41,712,121, with 70,840 diagnosed cases of DRF. The incidence rate of DRF before COVID-19 was 184.43 per 100,000 population, compared to 169.83 per 100,000 population during COVID-19. The details of incidence rate are shown in Table 2.

Comparison between before and during COVID-19 groups

Operation rate and type of surgery

Before COVID-19, 83.3% (58,146 out of 69,794) of patients underwent operative management. During COVID-19, this proportion increased to 86.9% (61,552 out of 70,840). The details of the operative techniques are summarized in Table 3. Open reduction and internal fixation was the most

Table 1. Characteristics of the general population by group: before and during COVID-19

Variable	Group 1 (2017–2018)	Group 2 (2020–2021)	Total
All	37,844,101 (47.6)	41,712,121 (52.4)	79,556,222 (100)
Sex			
Male	17,821,359	19,705,470	37,526,829 (47.2)
Female	20,022,742	22,006,651	42,029,393 (52.8)
Age (yr)			
50–59	16,852,520	17,110,074	33,962,594 (42.7)
60–69	11,202,543	13,436,647	24,639,190 (31.0)
70–79	6,625,654	7,257,273	13,882,927 (17.5)
≥80	3,163,384	3,908,127	7,071,511 (8.9)
Residence			
Metropolis	16,548,301	17,843,342	34,391,643 (43.2)
Others	21,295,800	23,872,219	45,168,019 (56.8)

Values are presented as number (%).

commonly performed modality, accounting for 70.7% of cases overall, and was more frequently performed during COVID-19 (76.5%, group 2) compared to before COVID-19 (64.8%, group 1).

Table 2. Incidence rate per 100,000 population a year

Variable	Group 1 (2017–2018)	Group 2 (2020–2021)	Total
All	184.43	169.83	176.77
Sex			
Male	64.98	62.59	63.73
Female	290.73	265.86	277.71
Age (yr)			
50–59	100.55	83.94	92.19
60–69	206.20	193.53	199.29
70–79	279.04	244.51	260.99
≥80	355.95	325.68	339.22
Residence			
Metropolis	173.96	164.50	169.05
Others	192.56	173.79	182.64

Table 3. Operation rate and details of surgical techniques

Variable	Group 1 (2017–2018)	Group 2 (2020–2021)	Total
All	69,794 (100)	70,840 (100)	140,634 (100)
Surgery			
No	11,648 (16.7)	9,288 (13.1)	20,936 (14.9)
Yes	58,146 (83.3)	61,552 (86.9)	119,698 (85.1)
Type of surgery	58,146 (100)	61,552 (100)	119,698 (100)
OR + plating	45,226 (77.8)	54,209 (88.1)	99,435 (83.1)
N0603	462 (0.8)	15 (0.0)	477 (0.3)
N0607	5,526 (9.5)	50 (0.1)	5,576 (4.7)
N0613	431 (0.7)	12 (0.0)	443 (0.4)
N0617	4,004 (6.9)	5 (0.0)	4,009 (3.4)
N1601	16,653 (28.6)	20,825 (33.8)	37,478 (31.3)
N1603	1,247 (2.1)	1,652 (2.7)	2,899 (2.4)
N1611	15,491 (26.6)	29,019 (47.2)	44,510 (37.2)
N1613	1,412 (2.4)	2,631 (4.3)	4,043 (3.4)
CR + pinning	8,414 (14.5)	5,076 (8.3)	13,490 (11.3)
N0993	2,131 (3.7)	9 (0.0)	2,140 (1.8)
N0994	252 (0.4)	1 (0.0)	253 (0.2)
N0996	5,518 (9.5)	4,582 (7.4)	10,100 (8.4)
N0998	513 (0.9)	484 (0.8)	997 (0.8)
External fixator	4,506 (7.8)	2,267 (3.7)	6,773 (5.7)
N0983	4,506 (7.8)	2,267 (3.7)	6,773 (5.7)

Values are presented as number (%).
OR, open reduction; CR, closed reduction.

Other demographics

Table 4 presents and compares the outcomes before and during COVID-19. Although statistical significance was observed for several variables (sex, P<0.0001; age, P<0.0001, income, P<0.0002; surgery rate, P<0.0001; CCI score, P<0.0001), these differences were not considered clinically meaningful due to the large sample size and were therefore not emphasized in the table. Nevertheless, residence (P=0.47) and mortality rate (P=0.15) did not show signif-

Table 4. Comparison of patients with distal radius fracture between groups

Variable	Group 1 (2017–2018)	Group 2 (2020–2021)	Total
All	69,794 (49.6)	70,840 (50.4)	140,634 (100)
Year			
2017	34,605 (49.6)	-	34,605 (24.6)
2018	35,189 (50.4)	-	35,189 (25.0)
2020	-	33,816 (47.7)	33,816 (24.0)
2021	-	37,024 (52.3)	37,024 (26.3)
Sex			
Male	11,581 (16.6)	12,333 (17.4)	23,914 (17.0)
Female	58,213 (83.4)	58,507 (82.6)	116,720 (83.0)
Mean age (yr)	68.1±10.2	68.7±10.8	68.4±10.2
Age (yr)			
50–59	16,946 (24.3)	14,363 (20.3)	31,309 (22.3)
60–69	23,100 (33.1)	26,004 (36.7)	49,104 (34.9)
70–79	18,488 (26.5)	17,745 (25.0)	36,233 (25.8)
≥80	11,260 (16.1)	12,728 (18.0)	23,988 (17.1)
Income			
1 (lowest)	4,151 (5.9)	4,078 (5.8)	8,229 (5.9)
2	13,670 (19.6)	13,855 (19.6)	27,525 (19.6)
3	14,604 (20.9)	15,446 (21.8)	30,050 (21.4)
4	21,103 (30.2)	20,885 (29.5)	41,988 (29.9)
5 (highest)	16,266 (23.3)	16,576 (23.4)	32,842 (23.4)
Residence			
Metropolis	28,787 (41.2)	29,353 (41.4)	58,140 (41.3)
Others	41,007 (58.8)	41,487 (58.6)	82,494 (58.7)
Surgery			
Yes	58,146 (83.3)	61,552 (86.9)	119,698 (85.1)
Death within 1 year			
Yes	923 (1.3)	1,000 (1.4)	1,923 (1.4)
CCI score			
0	16,340 (23.4)	18,242 (25.8)	34,582 (24.6)
1	20,284 (29.1)	19,798 (27.9)	40,082 (28.5)
2	14,778 (21.2)	14,366 (20.3)	29,144 (20.7)
3	8,499 (12.2)	8,524 (12.0)	17,023 (12.1)
4	4,957 (7.1)	5,033 (7.1)	9,990 (7.1)
≥5	4,936 (7.1)	4,877 (6.9)	9,813 (7.0)

Values are presented as number (%) or mean±standard deviation.
CCI, Charlson comorbidity index.

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icant differences between the two groups, even with the large sample size.

Discussion

Key results

Our findings showed that Korea exhibited a distinctive pattern during the pandemic, characterized by a decrease in fracture incidence but a simultaneous increase in surgical management compared with the prepandemic period. This study also provides valuable insight into the national epidemiology and management patterns of DRFs in South Korea. DRFs in the older adult population—predominantly female—often result from low-energy trauma, such as trivial daily activities.

Interpretation

Age and gender have a pronounced effect on the incidence rates of DRFs in the older adults [9,10]. The most frequent age group was 60–69 years, and women were significantly more likely than men to experience DRFs both before (2.61 times) and during (2.50 times) COVID-19 (Table 4). The incidence rate begins to rise after the age of 50 and nearly doubles with each subsequent decade (Table 2).

Our study had several strengths. First, we analyzed a large dataset containing whole national population provided by the NHIS, which ensures the reliability and generalizability of the findings. The comprehensive scope of the data allowed for an in-depth analysis of epidemiological and management trends in DRFs among the older adults. To our knowledge, there was no nationwide database study comparing the incidence and other demographics of DRF before and during COVID-19 pandemic in South Korea. Second, the data collected were based on a nationwide population, and there was the least chance of selection bias, providing insight to the current management of DRFs in South Korea. Additionally, the study's focus on a specific and vulnerable age group provides valuable insights into the effects of the COVID-19 pandemic on healthcare access and treatment outcomes.

The reduced numbers of orthopedic fractures, including DRFs, during the COVID-19 pandemic can be explained by lockdown measures, reduced physical activity, and prolonged indoor confinement. The older adults stayed mostly at home due to fears of infection. Some of them did not seek medical attention despite their injury and let it heal without any orthopedic intervention. Poggetti et al. [11] reported a 28.6% decrease in the number of patients undergoing surgery due to hand and wrist trauma in one of the Italian hospitals during the COVID-19 pandemic. In one of the Turkish hospitals, the total number of fractures recorded during the COVID-19 pandemic was by 61.6% lower than the number of fractures recorded in 2019 [12].

Consistent with previous Korean data, this study also demonstrated age-related differences in DRF epidemiology. Kwon et al. [13] reported that the incidence of DRFs steadily increases with advancing age, reflecting their nature as fragility fractures typically caused by low-energy trauma. In our study, the incidence in the 50–59 age group declined during the COVID-19 pandemic compared with the prepandemic years. This may be explained by the fact that relatively younger older adults, who are usually more active, experienced restricted outdoor and leisure activities during the pandemic. In contrast, older adults continued to sustain DRFs at home through trivial falls, which may have contributed to the relatively higher proportion of advanced-age patients during the COVID-19 pandemic.

Since the introduction of volar locking plate fixation in the early 2000s, there has been a notable shift toward more operative treatments [14-16]. Despite this ongoing trend, we anticipated a temporary decline in surgical rates during the COVID-19 pandemic because of reduced access to medical care. Contrary to our expectation, however, the surgical proportion of DRFs in Korea actually increased. A US analysis similarly reported a slight rise in surgical management from 2019 to 2020 (50.2% to 52.0%), although the underlying causes remain unclear due to various confounding factors, such as quarantine guidelines, supply chain disruptions, and resource limitations [17]. This pattern suggests that the rise in surgical proportion may reflect an ongoing nationwide trend toward operative fixation, rather than a direct effect of the COVID-19 pandemic.

In Korea, the surgical rate has consistently exceeded global levels, even during the COVID-19 pandemic [5,18]. This resilience reflects the strong accessibility of the healthcare system, supported by universal insurance coverage, relatively low copayments (20%–30%), and widespread private insurance [19,20]. The increased proportion of ORIF and relative decline in nonoperative cases suggest that patients with more severe fractures continued to seek hospital care, while minor nondisplaced cases may have been treated at home or miscoded as other injuries. Consequently, the surgical proportion appeared to rise despite an overall reduction in emergency visits.

Regarding operative modalities, previous reports from South Korea have indicated an increasing trend in volar locking plate fixation [21]. Consistently, this study found that the most common type of surgery for DRFs was ORIF, predominantly using an anatomic volar locking plate. The proportion of plate fixation increased from 77.8% before COVID-19 to 88.1% during COVID-19 (Table 3). Interestingly, the proportion of plate fixation in Korea is higher than that reported in the United States and other countries [22]. Although the use of external fixators for DRFs was already low before the COVID-19 pandemic (7.8%), it decreased even further during the pandemic period (3.7%).

Limitations

Despite analyzing a large dataset from the NHIS-NSC repository, several limitations were unavoidable. First, while this study reported increased rates of surgical intervention before and during the COVID-19 pandemic, the reasons behind these changes remain unclear and cannot be fully explained. Second, bilateral injuries were not addressed in this study, which may have led to an underestimation of the incidence rate and other outcomes. Third, the nationwide nature of the data also meant that patient-reported outcomes or quality-of-life measures were unavailable, limiting the ability to assess the broader clinical impact of the observed management changes. Finally, as a nationwide observational study, this research does not provide specific treatment guidelines.

Clinical implications

Nevertheless, this study is the first attempt to identify changes in the incidence and treatment trends of DRFs before and during the COVID-19 pandemic in South Korea using a national database. The findings highlight the importance of reflecting on our experiences and preparing for unexpected crises, such as future pandemics. By learning from the challenges of the COVID-19 pandemic, we can develop more effective strategies to address the healthcare needs of vulnerable populations during similar crises in the future.

Generalizability

This nationwide claims-based study is likely generalizable to Korean adults aged 50 years and older who are covered by the National Health Insurance system, as the database captures virtually all reimbursed healthcare encounters at the population level. However, extrapolation to other countries should be approached with caution due to differences in population age structure, fracture risk profiles, healthcare access, reimbursement policies, and coding practices.

Conclusions

During the COVID-19 pandemic, the incidence of DRFs has decreased in South Korea. However, the rate of surgical treatment has increased, which is higher than the global surgical rate. While the decrease of incidence seems attributable to pandemic-related behavioral changes, the higher surgical proportion likely reflects preexisting national trends rather than a direct COVID-19 effect.

Article Information

Author contributions

Conceptualization: HKY, SC. Data curation: SRY, KBH, YJ, JKL. Funding: SC. Formal analysis: SRY, YJ. Project administration: SC. Supervision: JKL, SC. Writing-original draft: HKY, KBH, SC. Writing-review & editing: HKY, SRY, YJ, JKL, SC. 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

Contact the corresponding author for data availability.

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Supplementary materials

Supplementary materials related to this article can be found online at https://doi.org/10.12671/jmt.2025.00297.

Supplement 1. ICD codes and NHIS prescription codes for distal radius fracture.

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Association between decreased bone mineral density and Pauwels angle in femoral neck fractures: a cross-sectional study

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Background: Progressive osteoporosis reduces the trabecular structures of the proximal femur, whereas the primary compression trabeculae (PCTs) are relatively preserved. We hypothesize that the loss of the vertically oriented PCTs in osteoporosis, which act as a mechanical barrier, affects fracture line propagation and influences the Pauwels angle. This study investigated the association between bone mineral density (BMD) and Pauwels angles in low-energy femoral neck fractures (FNFs).

Methods: This cross-sectional study included 150 patients (mean age, 75.3 years; range, 50–94 years) diagnosed with intracapsular FNFs between May 2019 and May 2023. BMD was measured within 1 month of the injury date using dual-energy X-ray absorptiometry, and modified Pauwels angles were assessed using a computed tomography-based multiplanar reconstruction program. Multiple linear regression analysis was performed to evaluate the factors influencing the Pauwels angles. The dependent variable was the Pauwels angle, while the independent variables included sex, age, height, body weight, body mass index, American Society of Anesthesiologists score, Charlson comorbidity index score, smoking status, alcohol use, preinjury walking ability, and femoral neck BMD T-scores.

Results: Higher femoral neck BMD T-scores were significantly associated with increased Pauwels angles (B=3.449, P<0.001). Greater body weight was independently associated with increased Pauwels angles (B=0.213, P=0.007).

Conclusions: The Pauwels angle demonstrated a significant association with BMD, with lower BMD associated with less steep Pauwels angles. In the absence of BMD measurement, the Pauwels angle may indicate osteoporosis severity in patients with low-energy FNFs.

Level of evidence: III.

Keywords: Body mass index; Femoral neck fracture; Osteoporosis; Bone density; Biomechanical phenomena

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Introduction

Background

The global incidence of hip fractures is increasing rapidly due to population aging, with femoral neck fractures (FNFs) accounting for approximately 49%–53% of hip fractures [1,2]. By 2050, hip fractures are projected to double that of 2018, presenting significant socioeconomic and healthcare challenges [3,4]. In the older population, nearly 90% of hip fractures result from low-energy trauma, a major consequence of osteoporosis [5-7].

The demographic shift raises medicolegal challenges. It requires distinguishing whether fractures are caused by trauma or osteoporosis-related fragility, particularly when osteoporosis is cited to justify reduced compensation [8]. However, without dual-energy X-ray absorptiometry (DXA) scans performed near the time of injury, assessing the contribution of osteoporosis to fractures remains challenging.

Osteoporosis is characterized by reduced bone mineral density (BMD) and a weakened trabecular structure [9,10]. As osteoporosis progresses, the trabecular structures in the proximal femur gradually diminish; however, the primary compression trabeculae (PCT)—the principal load-bearing structure—are the least affected [11,12]. Nevertheless, their eventual degradation significantly reduces the bone strength in the PCT region [12]. Biomechanical studies of human bones indicate that fracture propagation typically follows paths requiring minimal energy, either through structural weak points near barriers such as osteons or parallel to the bone's longitudinal axis, potentially influencing fracture patterns [13-15].

Therefore, the vertically oriented PCT may act as mechanical barriers, potentially redistributing the stress and guiding the fracture lines. Thus, higher BMD, supported by dense PCT, is hypothesized to guide fracture lines more vertically, resulting in increased Pauwels angles. In contrast, with decreasing BMD, these structural constraints weaken, leading to more horizontal fracture lines and decreased Pauwels angles.

Objectives

The association between decreased BMD and fracture risk is well established [16,17]. However, the effect of low BMD on fracture morphology, particularly its influence on the Pauwels angle in low-energy FNFs, remains underexplored. Thus, this study aimed to evaluate the association between BMD and the Pauwels angle in low-energy FNFs. We hypothesize that a lower BMD is associated with less steep (decreased) Pauwels angles.

Methods

Ethics statement

This study was approved by the Institutional Review Board (IRB) of Inje University Busan Paik Hospital (IRB No. 2025-01-010). The requirement for informed consent was waived by the IRB because of the retrospective design and use of anonymized data.

Study design

It was a cross-sectional study. It was described according to the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement available at: https://www.strobe-statement.org/.

Setting

This study was conducted at Inje University Busan Paik Hospital, Busan, Korea.

Participants

Data from 262 patients diagnosed with intracapsular FNFs between May 2019 and May 2023 were retrospectively reviewed. The inclusion criteria were as follows: diagnosis of subcapital or transcervical FNFs; age ≥50 years; and fractures resulting from low-energy trauma. The exclusion criteria were as follows: pathologic fractures; absence of BMD assessment within 1 month of injury or no BMD measurement performed; history of contralateral hip surgery causing implant artifacts; and contralateral hip bone deficits following implant removal, leading to artifacts that affect BMD measurements. Fractures caused by ground-level falls were defined as low-energy fractures [18]. After excluding patients, 150 patients were enrolled in this study.

Variables

The primary outcome variable was the modified Pauwels angle measured on CT-based multiplanar reconstruction images. The main exposure of interest was femoral neck BMD (T-score), and potential confounders included age, sex, height, body weight, body mass index (BMI), American Society of Anesthesiologists (ASA) score, Charlson Comorbidity Index (CCI) [19], smoking status, alcohol use, and preinjury walking ability (categorized as independent or not independent).

Data sources/measurement

Data were selected from the electronic medical records of the Inje University Busan Paik Hospital.

Modified Pauwels angle measurement

The RadiAnt DICOM Viewer (Medixant) was used to import computed tomography (CT) Digital Imaging and Communications in Medicine files and generate three-dimensional multiplanar reconstruction images to assess the lower extremity deformities associated with the fracture and establish the mid-coronal plane. In the axial plane, the head-neck axis (HNA) was determined using a line of the best-fit method through the center of the femoral neck isthmus to correct the external rotation deformity and femoral neck anteversion [20]. The mid-coronal plane was constructed as the plane containing the HNA and orthogonal to the axial plane, bisecting the femoral neck into the anterior and posterior regions. In the sagittal plane, the anatomical axis of the proximal femur was used to adjust the alignment of the mid-coronal plane to correct the lower extremity deformity and restore anatomical alignment. The Pauwels angle was measured on the reconstructed mid-coronal plane as the angle between the fracture line and a line perpendicular to the central line of the femoral shaft using a modified method (Fig. 1) [20,21]. The modified Pauwels angles were measured by two orthopedic surgeons who performed repeated measurements on the same images with a 3-week interval to assess intraobserver reliability. Consistency among raters was evaluated using intraclass correlation coefficients (ICCs), interpreted as <0.5 indicating poor reliability; 0.5–0.75, fair reliability; 0.75–0.9, good reliability; and >0.9, excellent reliability. In this study, the ICC values for the intra- and interobserver reliabilities ranged from 0.751 to 0.824 (Table 1).

BMD assessment

BMD measurements were performed using the Hologic Horizon W DXA Scanner (Hologic Inc.). Femoral neck BMD T-scores were assessed from the contralateral hip, assuming that it provides a reliable estimate of the BMD on the injured side. All measurements were conducted within 1 month of the injury to minimize temporal changes [22]. In this study, the World Health Organization's definitions of osteoporosis were used: T-scores ≥–1 represent normal BMD, T-scores between –1 and –2.5 indicate osteopenia, and T-scores ≤–2.5 define osteoporosis [23].

Bias

To reduce selection bias, all eligible consecutive patients who met the inclusion and exclusion criteria during the study period were included. Measurement bias was min-

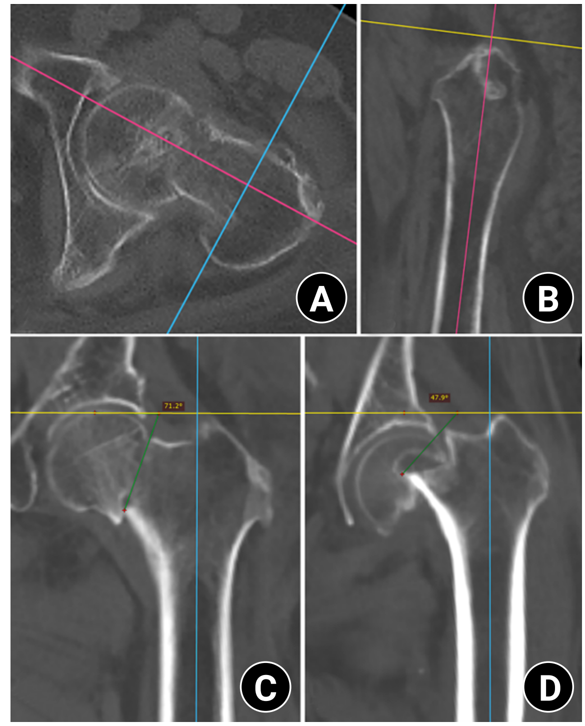

Fig. 1. Modified Pauwels angle measurement using multiplanar reconstruction. (A) The head-neck axis (HNA; pink line) was identified in the axial plane using the line of the best-fit method through the center of the femoral neck isthmus. This process corrected the external rotation deformity and femoral neck anteversion. The mid-coronal plane was defined as the plane containing the HNA and oriented perpendicular to the axial plane, dividing the femoral neck into anterior and posterior regions. (B) The sagittal plane was utilized to adjust the alignment of the mid-coronal plane using the anatomical axis of the proximal femur. This adjustment corrected the lower extremity deformities and restored proper anatomical alignment. (C) The modified Pauwels angle was measured on the reconstructed mid-coronal plane as the angle between the fracture line (green line) and a line perpendicular (yellow line) to the central line of the femoral shaft (blue line). A 79-year-old female patient with a femoral neck T-score of –1.7 sustained a ground-level fall, resulting in a modified Pauwels angle of 71.2°. (D) In contrast, an 83-year-old female patient with a femoral neck T-score of –4.2 exhibited a modified Pauwels angle of 47.9° in the reconstructed mid-coronal plane.

Table 1. Intraobserver and interobserver reliability for modified Pauwels angle measurements

Observer	Intraobserver reliability (95% CI)	Interobserver reliability (95% CI)
A	0.817 (0.747–0.869)	0.751 (0.657–0.820)
B	0.824 (0.757–0.872)	

CI, confidence interval.

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imized by using a standardized CT-based protocol for Pauwels angle measurement and by performing BMD assessments with a single DXA scanner within one month of injury.

Study size

No formal sample size calculation was performed; instead, the study included all eligible patients with low-energy intracapsular FNFs treated at our institution between May 2019 and May 2023.

Quantitative variables

Age, body weight, BMI, and Pauwels angle were treated as continuous variables in the regression analyses, whereas preinjury walking ability was entered as a binary categorical variable (independent vs. not independent).

Statistical methods

IBM SPSS ver. 27.0 (IBM Corp.) was used for the statistical analysis. Significance was set at P<0.05. Stepwise multiple linear regression analysis was conducted to evaluate the factors that affect the Pauwels angles. The dependent variable was the Pauwels angle, while the independent variables included sex, age, height, body weight, BMI, ASA score, CCI score, smoking status, alcohol use, preinjury walking ability, and femoral neck BMD T-scores. Forward stepwise logistic regression was performed to construct an osteoporosis prediction model incorporating the Pauwels angle.

There were no missing data for the variables included in the regression analyses. No subgroup, interaction, or sensitivity analyses were performed.

Results

Participants

The patient flow chart is shown in Fig. 2.

Patient characteristics

Patient demographics and baseline characteristics are shown in (Table 2). Among the 150 patients, women comprised 69.3%, and the mean age was 75.3 years (range, 50–94 years). The mean femoral neck BMD T-score was −2.6 (range, −4.5 to −0.4). According to the WHO criteria, 96.7% of the patients exhibited either osteopenia (40.7%) or osteoporosis (56.0%). The mean Pauwels angle was 58.5° (range, 38.7°–78.7°). Most fractures were displaced and classified as Garden types 3 or 4 (89%).

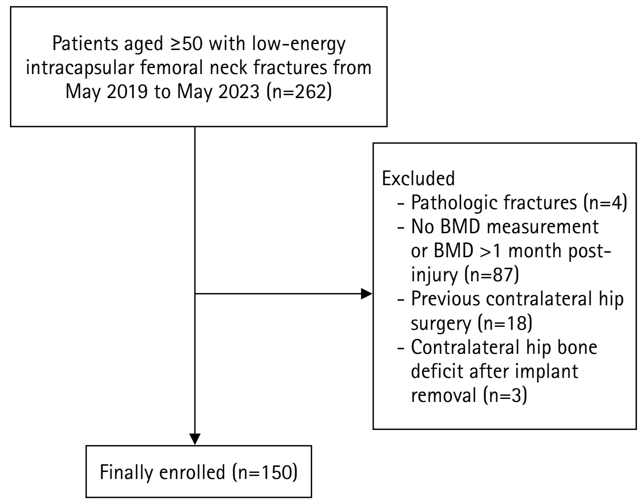

Fig. 2. Flowchart of patient selection. BMD, bone mineral density.

Table 2. Patient demographics and baseline characteristics (n=150)

Characteristic	Value
Sex (male:female)	46:104
Age (yr)	75.3±9.7 (50–94)
Involved hip (right:left)	82:68
Height (cm)	160.1±8.5 (143–187)
Weight (kg)	56.0±9.5 (34–80)
Body mass index (kg/m^2)	21.9±3.3 (13.6–32.5)
ASA score	2.6±0.5
CCI	4.0±1.4
Smoking	38 (25.3)
Alcohol use	25 (16.7)
Preinjury walking ability	
Independent	96 (64)
Not independent	54 (36)
BMD T-score, femoral neck	−2.6±0.8 (−4.5 to −0.4)
WHO definition	
Normal	5 (3.3)
Osteopenia	61 (40.7)
Osteoporosis	84 (56.0)
Pauwels angle (°)	58.5±9.3 (38.7–78.7)
Garden type (1/2/3/4)	4/12/32/102

Values are presented as mean±standard deviation (range) or number (%).
ASA, American Society of Anesthesiologists physical status; CCI, Charlson comorbidity index; BMD, bone mineral density; WHO, World Health Organization.

Association between BMD and the Pauwels angle

Multiple linear regression analysis (R^2=0.200) demonstrated that femoral neck BMD T-scores (B=3.449, P<0.001) and body weight (B=0.213, P=0.007) were significantly associated with the Pauwels angle (Table 3). No variable exhibited a variance inflation factor ≥2, indicating the absence of multicollinearity. Higher femoral neck BMD T-scores and greater body weight were independently associated with an increase in the Pauwels angle in low-energy FNFs (Fig. 3).

Prediction of osteoporosis using the Pauwels angle

Multivariate logistic regression analysis identified the Pauwels angle, sex, and age as significant independent predictors of osteoporosis in low-energy FNFs (all P<0.001) (Table 4). The receiver operating characteristic curve combining these factors yielded an area under the curve (AUC) of 0.839 (95% confidence interval [CI], 0.774–0.904; P<0.001), with a sensitivity of 81% (95% CI, 0.631–0.929) and a specificity of 77% (95% CI, 0.424–0.849) (Fig. 4). The model development and internal validation are described in the Supplement 1, and the calibration curve and nomogram are shown in Supplements 2 and 3, respectively.

Discussion

Key results

Among 150 participants, 96.7% had osteopenia or osteoporosis. The mean Pauwels angle was 58.5°. Linear regression showed femoral neck BMD T-scores (B=3.449, P<0.001) and, body weight (B=0.213, P=0.007) were significantly linked to the Pauwels angle. Multivariate analysis identified Pauwels angle, sex, and age as independent osteoporosis predictors. The combined model achieved an area under the curve of 0.839, with 81% sensitivity and 77% specificity. These results demonstrate the Pauwels angle correlates with bone density and effectively predicts osteoporosis in patients with low-energy FNFs.

Table 3. Multiple linear regression analysis of factors affecting the Pauwels angle (°) using the stepwise method

Independent variable	Unstandardized coefficient		Standardized coefficient (β)	P-value
	B	SE (B)		
BMD T-score (femoral neck)	3.449	0.88	0.314	<0.001
Weight (kg)	0.213	0.078	0.219	0.007

SE, standard error.

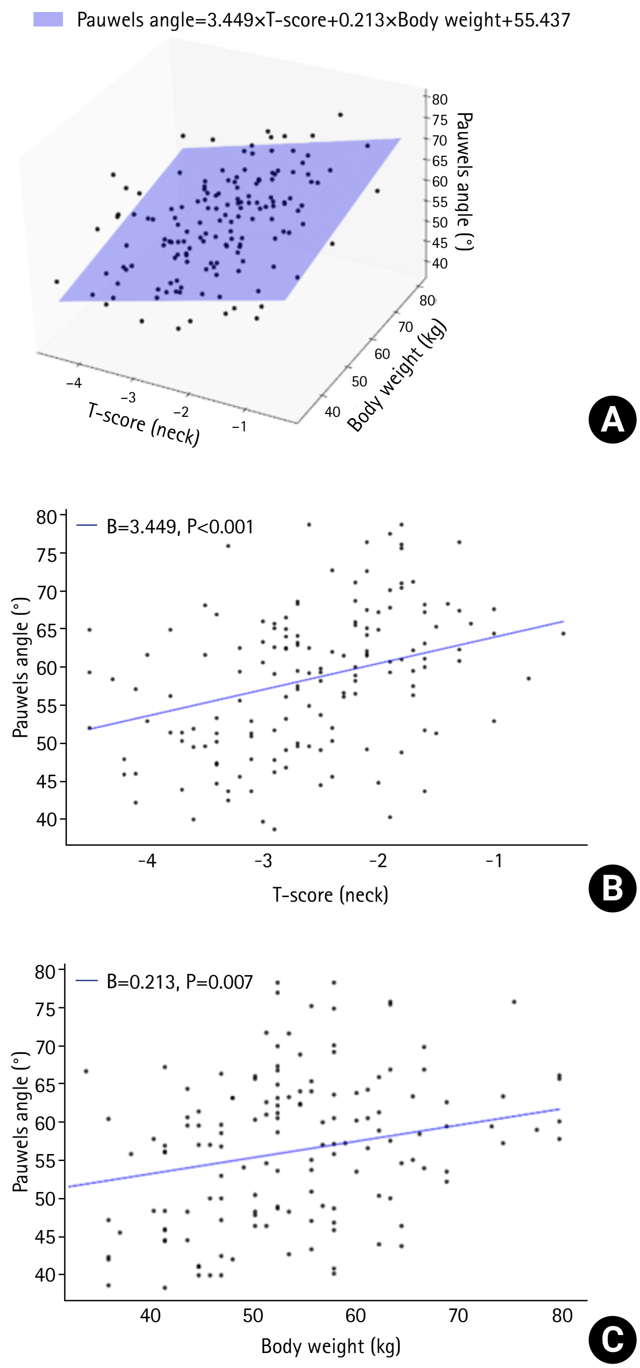

Fig. 3. Association between femoral neck bone mineral density (BMD) T-scores, body weight, and the Pauwels angle using multiple regression models. (A) Three-dimensional scatter plot showing the relationship between the T-score, body weight, and Pauwels angle with a regression surface. (B) Scatter plot of the T-score versus Pauwels angle, with a regression line fitted while the body weight is fixed at its mean value (56 kg). (C) Scatter plot of body weight versus the Pauwels angle, with a regression line fitted while the T-score is fixed at its mean value (–2.6). All individual data points are displayed.

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Interpretation/comparison with previous studies

Fractures typically propagate along paths requiring the least energy, often following structural weak points [13-15]. Nalla et al. [14] demonstrated that cracks in the cortical bone propagate along osteons, which act as structural barriers. Similarly, Taylor et al. [15] reported that in the cancellous bone, microcracks align with the bone's longitudinal axis, whereas cortical bone cracks encountering barriers such as osteons change direction. In the proximal femur, the PCT likely acts as a similar mechanical barrier, redistributing the stress to guide fracture propagation. Our findings support this mechanism. When BMD is high, preserved PCT guide fracture lines vertically, leading to steeper Pauwels angles. As osteoporosis progresses, PCT are lost and these barriers weaken. This is consistent with the decreased Pauwels angles observed in patients with low BMD (Fig. 5).

Table 4. Multivariate logistic regression analysis identifying independent predictors of the presence of osteoporosis (yes/no)

Independent variable	OR (95% CI)	P-value
Pauwels angle (°)	0.91 (0.87–0.96)	<0.001
Sex (female; reference, male)	4.81 (1.20–11.58)	<0.001
Age	1.10 (1.05–1.15)	<0.001

OR, odds ratio; CI, confidence interval.

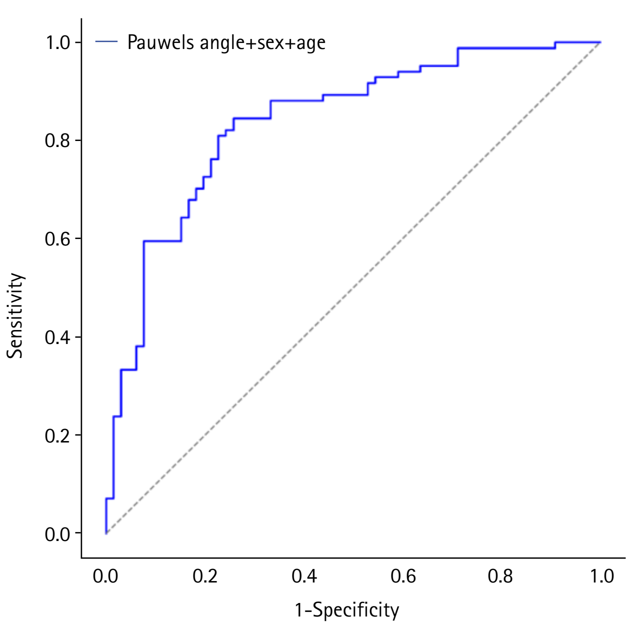

Fig. 4. Receiver operating characteristic curve for the combined model incorporating the Pauwels angle, sex, and age in predicting osteoporosis (area under the curve, 0.839).

Osteoporosis significantly increases the risk of hip fractures due to BMD reduction and trabecular deterioration [9,10,16,17]. Recent quantitative studies have shown that PCT is least affected by osteoporosis-induced changes compared with other trabecular regions [11,12]. Bot et al. [11] reported that Ward's triangle showed the most significant resorption, whereas the PCT remained relatively preserved. Feng et al. [12], using micro-CT and finite-element analysis, confirmed that PCT degradation occurs more slowly than in other regions, reducing bone strength in the PCT. However, no direct biomechanical studies have validated the relationship between trabecular loss and fracture propagation. Thus, future studies using advanced imaging and biomechanical models are needed to confirm this relationship.

This study also identified a significant positive association between body weight and Pauwels angles. Although the injury mechanism differs from that of high-energy trauma commonly seen in young adults with FNFs, which is associated with vertical Pauwels angles—such as an automobile accident or a fall from a great height, where direct axial loading is transmitted along the femur to the pelvis [20,24]—it highlights how greater body weight in low-energy mechanisms, like a lateral fall from standing height, can influence fracture patterns through increased trauma energy. Increased body weight contributes to greater trauma energy during falls, as described by the equations for

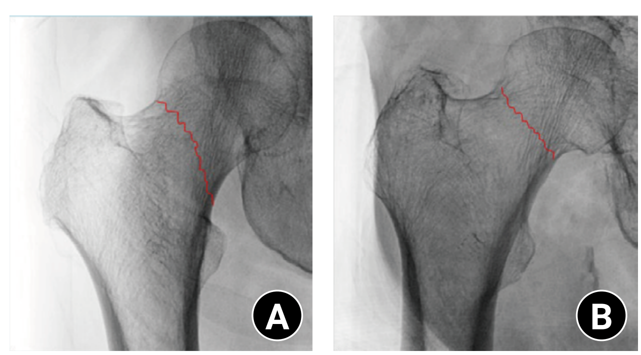

Fig. 5. Relationship between the Pauwels angle and bone mineral density (BMD). (A) Radiograph of a female patient with relatively high BMD (T-score, –1.5). The preserved primary compression trabeculae (PCTs) are associated with a vertically oriented fracture line, resulting in a steeper Pauwels angle. (B) Radiograph of a female patient with low BMD due to advanced osteoporosis (T-score, –4.5). Loss of PCTs leads to a more horizontally oriented fracture line and a decreased Pauwels angle.

kinetic and potential energy. Mechanically, this suggests that a higher body weight increases the force transmitted to the femoral neck, potentially resulting in steeper Pauwels angles. Although protective factors such as muscle mass or subcutaneous padding may mitigate this force, they are likely insufficient to counteract the dominant effect of trauma energy. Furthermore, the specific contributions of the body composition remain unclear, complicating its protective role [25]. These findings underscore body weight as an independent determinant of fracture morphology, distinct from the previously established association between lower body weight, BMI, and fracture risk [26-28].

To the best of our knowledge, only one study has used a CT-based image reconstruction program for accurately measuring the modified Pauwels angle, which effectively eliminates projection errors. Kong et al. [21] included patients aged <65 years and measured the modified Pauwels angle regardless of the trauma energy. In the reformatted CT coronal images, the average Pauwels angle was 68.7° (all classified as Pauwels type II or III). In contrast, the present study reported a lower average Pauwels angle of 58.5° (range, 38.7°–78.7°), which likely due to the older patient cohort and inclusion of only low-energy trauma cases.

In this study, the highest Pauwels angle was 78.7°. Recently, Xu et al. [29] conducted a CT-based quantitative analysis of PCT among the elderly and reported a minimum PCT angle of 3.44°, relative to the proximal anatomical femoral axis. When adjusted for comparison with the modified Pauwels angle, this corresponded to 93.44°, which is comparable to the highest Pauwels angle observed in this study and to the highest angle (91.2°) reported by Kong et al. [21]. While a direct numerical match is not expected due to variability in fracture propagation, these findings support the hypothesis that a dense PCT, indicative of higher BMD, acts as a barrier to fracture propagation along or within the original PCT axis. Pauwels type I fractures (<30°) are exceptionally rare. Given the inclination of the femoral neck axis relative to the proximal anatomical femoral axis, defined as the neck shaft angle, such low-angle fractures would require an unusual trajectory involving the greater trochanter or medial extension to the femoral head. Although some biomechanical models reference Pauwels angles of 30°, to our knowledge, no clinical cases of type I fractures measured using reformatted CT planes have been reported, aligning with our findings [30,31].

Previous studies evaluating Pauwels angle or fracture morphology in osteoporotic FNFs are limited. Thirunthaiyan et al. [32] reported that transcervical fractures were more frequent in patients with Singh index 4, whereas subcapital fractures predominated in those with Singh index 3. Similarly, Heetveld et al. [33] similarly demonstrated that the proportion of Pauwels type III fractures was higher in patients with normal BMD or osteopenia compared to those with osteoporosis. These results are in partial agreement with our findings, suggesting that increasing osteoporosis severity is associated with lower Pauwels angles. In contrast, Zhao et al. [34] reported a decreasing trend of Hounsfield units and femoral cortical index across Pauwels types I to III. However, these prior studies were limited by simple comparative analyses and relied on radiographic measurements rather than CT-based reformatted assessments of fracture classification.

In the present study, 96.7% of patients had either osteopenia or osteoporosis. Dhibar et al. [35] reported that 97.3% of patients with fragility hip fractures had either osteoporosis or osteopenia, while Bartels et al. [36] demonstrated comparable rates in osteoporotic FNFs (44% osteoporosis and 47% osteopenia). These findings highlight the consistently high prevalence of impaired bone quality in this population.

In this study, contralateral hip BMD was used because the fractured side cannot be reliably assessed at the time of injury. Previous studies indicate that although contralateral hips show high correlations in BMD, clinically meaningful asymmetries can still occur, limiting the precision of using one hip's BMD to represent the other. Yang et al. [37] reported strong correlations between contralateral hips, with coefficients ranging from 0.893 to 0.9 across the femoral neck, trochanter, and Ward's triangle. In contrast, Mounach et al. [38] found that in a cohort of 3,481 subjects, 52.1% of femoral neck measurements showed differences exceeding the smallest detectable difference. Lilley et al. [39] similarly demonstrated high correlation coefficients (0.91 for the femoral neck, 0.91 for Ward's triangle, and 0.84 for the trochanter), yet observed variations of up to 34% at the femoral neck, 64% at Ward's triangle, and 80% at the trochanter. Therefore, although contralateral BMD is widely used in fragility hip fracture research as a practical alternative [22,40], potential side-to-side differences should be acknowledged when interpreting the findings.

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Limitations

This study has several limitations. First, the R^2 value was 0.200 in the regression analysis, indicating that only 20% of the variance in Pauwels angle could be explained by the T-score and body weight. This limited explanatory power reduces its utility as a precise quantitative tool, and therefore, the results of this study must be interpreted cautiously. This limitation is likely due to individual variations in the proximal femoral geometry, fall direction and velocity, and PCT distribution. However, multivariate logistic regression analysis identified the Pauwels angle as a significant independent predictor of osteoporosis, alongside sex and age. A predictive model incorporating these factors demonstrated an AUC of 0.839, suggesting the Pauwels angle as a reliable predictor of osteoporosis in low-energy FNFs. Second, the retrospective, single-center design limit generalizability, and incomplete BMD data may introduce bias. Third, the BMD was measured from the contralateral hip, assuming that the BMD of the injured hip is likely similar to that of the uninjured site. Although this approach may have introduced bias, accurately measuring the BMD of the injured hip directly remains challenging. Local changes in BMD may occur over time, particularly after fractures and decreased ambulatory activity following surgery. To minimize the influence of temporal changes, our BMD measurements were obtained from the contralateral hip within one month following the fracture. Fourth, direct biomechanical validation of the relationship between BMD-related trabecular loss and fracture propagation was not performed. Future multicenter studies and biomechanical models using high-resolution imaging, such as micro-CT and finite-element analysis, are warranted to validate these findings. Fifth, this study should be considered exploratory and hypothesis-generating, and the findings will require confirmation in larger prospective studies.

Despite these limitations, this study demonstrates that the Pauwels angle is significantly associated with BMD, with lower femoral neck T-scores corresponding to less steep angles. The predictive model incorporating the Pauwels angle demonstrated promising results, further supporting its role as a reliable osteoporosis predictor. These findings suggest that the Pauwels angle could serve as an alternative indicator of bone fragility and BMD in low-energy FNFs at the time of injury.

Clinical implication

In South Korea, orthopedic experts are often required to determine whether FNFs in elderly patients are attributable to osteoporosis or to trauma itself. Our results suggest that basic demographic factors (age, sex) combined with fracture morphology, especially the Pauwels angle, can provide useful probabilistic estimates of underlying osteoporosis. This approach may assist orthopedic experts in providing evidence-based opinions in medicolegal and insurance disputes where only limited clinical data are available.

Conclusions

There was a significant association between the Pauwels angle and BMD in low-energy FNFs. Osteoporosis-related changes in PCT may influence fracture patterns. The Pauwels angle, combined with basic demographic factors, may serve as a practical surrogate marker of underlying osteoporosis when BMD assessment is unavailable.

Article Information

Author contributions

Conceptualization: SHJ. Data curation: JHP. Formal analysis: YUK. Investigation: SHJ. Methodology: YUK. Project administration: YUK. Software: JHP. Supervision: SHJ. Validation: YUK. Visualization: JHP. Writing-original draft: SHJ. Writing-review & editing: all authors. 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

Contact the corresponding author for data availability.

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Supplementary material

Supplementary materials related to this article can be found online at https://doi.org/10.12671/jmt.2025.00269.

Supplement 1. Logistic regression model for predicting osteoporosis.
Supplement 2. Calibration curve of the logistic regression model for the predicted probability of osteoporosis.
Supplement 3. Nomogram of the logistic regression model for the predicted probability of osteoporosis.

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Three-dimensional computed tomography-based differentiation of engaged versus displaced intertrochanteric fractures using the anterior fracture line: a cross-sectional study from Korea

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Background: Achieving stable fixation that enables early ambulation is essential but remains challenging because complex intertrochanteric (IT) fracture patterns are often underestimated on plain radiographs. Herein, we analyzed whether the anterior fracture line lies medial or lateral to the IT line and examined its relationship with displacement or distal medullary canal engagement.

Methods: A retrospective review was conducted on 96 osteoporotic IT fractures in patients aged ≥60 years treated between April 2013 and December 2022 at National Police Hospital and Asan Medical Center, Seoul, Korea. Fractures were classified as engaged, completely displaced, and partially displaced based on three-dimensional computed tomography findings. The anterior fracture-line position (medial or lateral to the IT line) and the status of the lesser trochanter (LT) were evaluated. The chi-square or Fisher exact test was used for statistical comparisons.

Results: In total, 96 patients were analyzed. Of these, 49 cases (51.0%) were classified as engaged type, 27 cases (28.1%) as completely displaced type, and 20 cases (20.8%) as partially displaced type. When comparing fracture pattern with anterior fracture-line position, the completely displaced type showed a significantly higher proportion of lateral anterior fracture lines than the other two types ($P<0.001$). However, no significant association was identified between fracture pattern and LT displacement. When the anterior fracture-line position and LT displacement were evaluated together, only the engaged type demonstrated a possible association between a lateral anterior fracture line and LT displacement ($P=0.047$).

Conclusions: Fracture lines lateral to the IT line were strongly associated with displacement in IT fractures; however, their relationship with LT involvement, reflecting iliopsoas tendon traction, was not clearly demonstrated. Although the factors contributing to the engaged-type fracture remain uncertain, the statistical association between fracture pattern and anterior fracture-line position suggests that capsular structures may play a stabilizing role in select fracture configurations.

Level of evidence: III, retrospective study.

Keywords: Hip fractures; X-ray computed tomography; Femur; Tendons

Original Article

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Introduction

Background

With the advent of an aging society, the prevalence of osteoporosis and the incidence of osteoporotic hip fractures have imposed a significant socioeconomic burden. According to recent Korean national data, the incidence of osteoporotic hip fractures increased by 138% between 2006 and 2010, and as of 2021, the 1-year mortality rate following hip fracture reached 18.2% [1], which is the highest among all osteoporotic fractures.

To prevent mortality and frequent postoperative complications associated with osteoporotic hip fractures, early postoperative ambulation is considered crucial [2]. A prerequisite for early ambulation is stable fracture fixation [3]. Achieving stable fixation requires an accurate understanding of fracture morphology, including the degree of comminution and displacement, and the selection of an appropriate internal fixation device.

Although the design and performance of internal fixation devices for osteoporotic fractures have improved over time, mechanical complications, such as lag screw cut-out or cut-through of the femoral head [4], resulting in fixation failure, remain unresolved. One major contributor to these complications is an insufficient understanding of fracture morphology [5]. In particular, intertrochanteric (IT) fractures are prone to fixation failure when treated without a precise understanding of the fracture pattern. Despite these limitations, many surgeons still rely primarily on plain radiographs for the diagnosis and classification of IT fractures. However, in many cases, additional fracture fragments not visible on X-rays can often be identified only using computed tomography (CT).

Current classification systems for IT fractures are largely based on plain radiographs and, therefore, do not fully capture the complexity of fracture morphology. This limitation may be partly attributable to the influence of the joint capsule and capsular ligaments. In South Korea, although CT scans have become more widely used for the diagnosis of IT fractures compared to the past, supporting evidence for the relationship with the joint capsule and capsular ligaments remains insufficient.

This study focused on two IT fracture patterns that have recently gained attention: the canal engagement and displaced types [5,6]. Anatomically, the joint capsule attaches to the mid-portion of the femoral neck posteriorly, whereas anteriorly, the capsular ligaments, such as the iliofemoral ligament, are relatively thick and long, attaching to the IT line. Although IT fractures are considered extra-articular, if the anterior fracture line lies proximal to the IT line, the capsule may remain attached to the distal fragment, rendering the anterior portion of the fracture intra-articular in nature. In such cases, the intact capsule may resist displacement of the proximal fragment, potentially leading to varus deformity and engagement of the inferior beak into the medullary canal of the distal fragment.

Objectives

This study aimed to assess, using three-dimensional (3D)-CT, whether the anterior part of an IT fracture lies medial (superior) or lateral (inferior) to the IT line, and to investigate the relationship between this anatomical location and the presence of displacement or canal engagement patterns. This analysis was also used to indirectly evaluate the potential role of the joint capsule and capsular ligaments in influencing fracture displacement.

Methods

Ethics statement

This study was approved by the Institutional Review Board (IRB) Ethics Committee of National Police Hospital (IRB No. 11100176-202507-HR-002). The requirement for informed patient consent was waived owing to the retrospective nature of the study, and all analyses were conducted using anonymized clinical data.

Study design and setting

It is a cross-sectional study. This study was conducted at National Police Hospital and Asan Medical Center, Seoul, Korea and included patients who underwent surgery for IT fractures performed by a single surgeon between April 2013 and December 2022.

Participants

Inclusion criteria were as follows: (1) patients aged ≥60 years with fragility-related IT fractures, and (2) availability of preoperative 3D-CT imaging. The exclusion criteria were as follows: (1) patients aged <60 years (n=21), (2) fractures resulting from high-energy trauma with severe comminution that made definition of the main fracture pattern difficult (n=8), (3) reverse oblique type fractures (n=8), and (4) undisplaced IT fractures (n=3). An initial screening identified 136 patients; applying the exclusion criteria, 96 hips in 96 patients met the inclusion criteria and were included in the analysis. The patient selection process is illustrated in Fig. 1.

Variables

The primary outcome was the CT-based displacement pattern, categorized into three groups: engaged type, completely displaced type, and partially displaced type. The primary exposure was the position of the anterior fracture line relative to the IT line, categorized as medial or lateral according to its location on 3D-CT. The secondary exposure was the displacement status of the lesser trochanter (LT), categorized as intact or displaced on 3D-CT. Baseline covariates included age, sex, body mass index, and bone mineral density T-score at admission, when available from dual-energy X-ray absorptiometry.

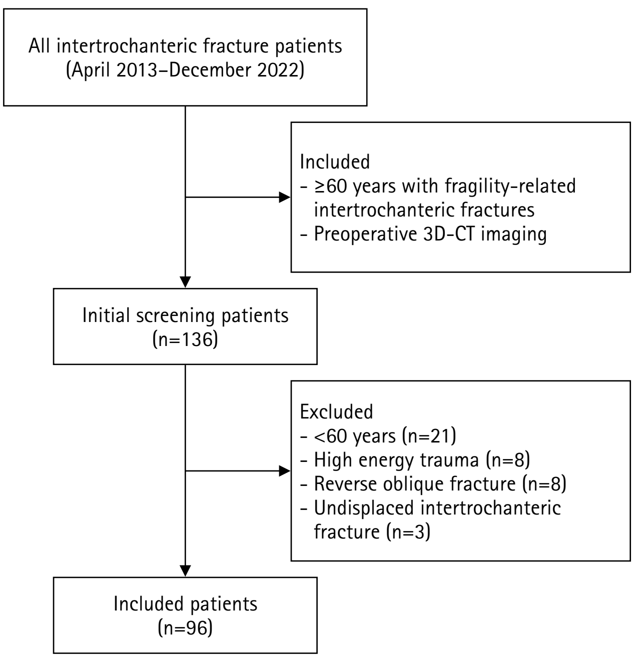

Fig. 1. Flowchart of patient selection. 3D-CT, three-dimensional computed tomography.

Data sources/measurement

Based on 3D-CT scans obtained from all 96 patients, previously established concepts of intramedullary and extramedullary positions of the proximal fracture fragment [7,8] were expanded to classify IT fractures into three types according to the location of the proximal head fragment: (1) engaged, (2) completely displaced, and (3) partially displaced.

The engaged type was defined as fractures in which the proximal head fragment was completely embedded into the medullary canal of the distal fracture part. The completely displaced type referred to fractures in which the proximal fragment was entirely outside the medullary canal. The partially displaced type represented an intermediate stage, where the inferomedial part of the fracture line showed minimal displacement, but the proximal portion was visibly displaced. Representative images of these types are presented in Fig. 2.

Following classification by 3D-CT, each fracture was fur-

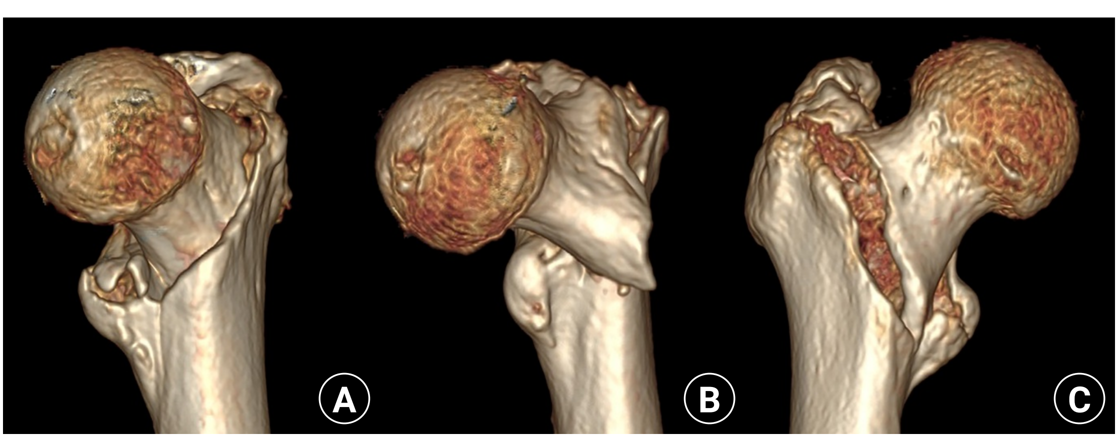

Fig. 2. Representative three-dimensional computed tomography images of intertrochanteric fractures: (A) engaged type, (B) completely displaced type, and (C) partially displaced type.

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ther subcategorized based on (1) the position of the anterior fracture line and (2) the displacement status of the LT.

The IT line, defined as a bony ridge on the femur that extends anteriorly over the neck of the femur [9], was identified on 3D-CT imaging in this study. For the anterior fracture line, its position relative to the IT line was used as the criterion: if the fracture line was located medial to the IT line, it was classified as the medial type, and if it was located lateral to the line, it was classified as the lateral type. Representative examples of these types are illustrated in Fig. 3.

Bias

Restricting inclusion to cases with preoperative 3D-CT may select for patients with more complex fractures. This selection bias was mitigated by screening consecutive surgical cases over a defined period and applying exclusion criteria.

Study size

No formal a priori sample size calculation was performed because the study was exploratory and based on available retrospective imaging data.

Statistical analysis

Categorical variables, including the location of the anterior fracture line (medial vs. lateral to the IT line) and the status of the LT (intact vs. displaced), were compared among the three displacement groups (engaged, completely displaced, and partially displaced). The overall (omnibus) comparison across the three groups was conducted using the Pearson chi-square test. When the omnibus test was significant, pairwise 2×2 Fisher exact tests were performed with Bonferroni adjustment for multiple comparisons (adjusted α=0.0167). Effect sizes were reported as odds ratios (95% confidence intervals) and Cramer's V for the omnibus association. Analyses were conducted using R ver. 4.3.2 (R Foundation for Statistical Computing) with the rcompanion and epitools packages. Statistical significance was defined as two-tailed P<0.05 (or Bonferroni-adjusted threshold for pairwise tests).

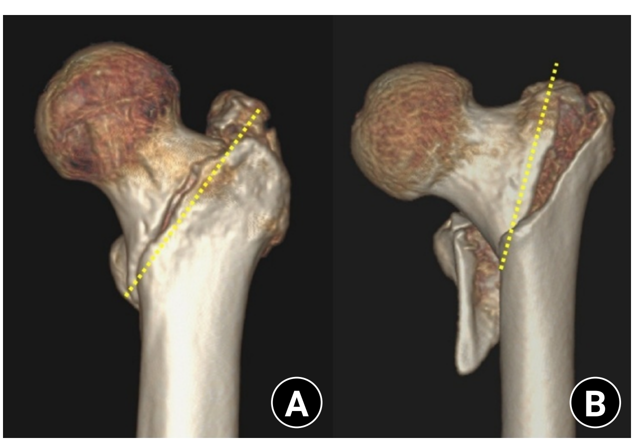

Fig. 3. Definition of the anterior fracture line. Based on the intertrochanteric line (yellow dotted line), representative examples are shown of fractures located (A) medial and (B) lateral to the line.

Results

Participants' characteristics

As for the baseline demographics, women were dominant, accounting for 72 of the 96 patients, and the mean age was 84.6 years. A total of 96 patients were analyzed: 49 cases (51.0%) were classified as the engaged type, 27 cases (28.1%) as the completely displaced type, and 20 cases (20.8%) as the partially displaced type. Additional demographic details are presented in Table 1.

Association between anterior fracture-line position and fracture displacement pattern

First, in the analysis of whether the position of the anterior fracture line differed significantly among the three fracture types, a significant difference was found in the distribution of anterior fracture-line location across the displacement groups (χ^2=14.27, df=2, P<0.001). Subsequent pairwise post-hoc testing revealed that the completely displaced

Table 1. Patient demographics

Characteristic	Value
Patient (hip)	96 (96 hips)
Sex (male:female)	24 (25):72 (75)
Age (yr)	84.6±11.2
BMI (kg/m^2)	22.5±2.7
T-score of BMD at admission period	−2.8±1.1
Fracture type	
Engaged	49 (51.0)
Partially displaced	20 (20.8)
Completely displaced	27 (28.1)

Values are presented as number (%) or mean±standard deviation.
BMI, body mass index; BMD, bone mineral density.

group had a markedly higher proportion of lateral anterior fracture lines (81.5%) compared with the engaged (44.9%, adjusted P=0.010) and partially displaced groups (30.0%, adjusted P=0.002) (Table 2).

Association between lesser trochanter displacement and fracture displacement pattern

In contrast, neither the overall comparison nor the pairwise comparisons demonstrated any significant association between fracture pattern and LT displacement. Detailed statistical results are presented in Table 3.

Combined analysis of anterior fracture-line position and lesser trochanter displacement

Finally, when the anterior fracture-line position and LT displacement were analyzed together in relation to the fracture pattern (Table 4), no significant associations were observed in any of the groups except for the engaged type, where a lateral anterior fracture line showed a significant relationship with LT displacement (P=0.047).

Table 2. Distribution of anterior fracture-line location (medial vs. lateral) according to the fracture type

Fracture type	Medial	Lateral	Row % lateral	Total
Engaged	27	22	44.9	49
Completely displaced	5	22	81.5	27
Partially displaced	14	6	30.0	20
Total	46	50	NA	96

Omnibus test: χ^2=14.27, df=2, P=0.0008 (Cramer's V=0.386).
Pairwise post-hoc (Fisher exact, Bonferroni-adjusted α=0.05/3=0.0167): (a) Completely displaced (81.5%) vs. engaged (44.9%): P=0.0032 (adjusted P<0.010); OR, 0.19 (95% CI, 0.06–0.57). (b) Completely displaced (81.5%) vs. partially displaced (30.0%): P=0.001 (adjusted P=0.002); OR, 0.10 (95% CI, 0.02–0.38). (c) Engaged (44.9%) vs. partially displaced (30.0%): P=0.291 (adjusted P=0.874); OR, 1.90 (0.63–5.77).
NA, not applicable; OR, odds ratio; CI, confidence interval.

Table 3. Lesser trochanter displacement following fracture type

Fracture group	LT intact	LT displaced	Row % displaced	Total
Engaged	21	28	57.1	49
Completely displaced	13	14	51.9	27
Partially displaced	14	6	30.0	20
Total	48	48	NA	96

Omnibus test: χ^2=4.24, df=2, P=0.120 (not significant). Although not statistically significant in the omnibus test, an exploratory pairwise comparison suggested a lower rate of LT displacement in the partially displaced group compared with the engaged group (30.0% vs. 57.1%, P=0.026, unadjusted; adjusted P=0.078 after Bonferroni correction).
LT, lesser trochanter; NA, not applicable.

Discussion

Key results

The findings revealed that in completely displaced IT fractures, the anterior fracture line was located significantly more lateral to the IT line. This indicates that extracapsular fractures are less likely to become engaged and are more prone to displacement. When both the anterior fracture line position and LT displacement were considered together, cases in which the anterior fracture line was lateral to the IT line and accompanied by LT displacement were significantly more frequent in the engaged type (P=0.047). This suggests that even when the fracture line is located laterally, displacement of the LT may eliminate structural support for the fracture fragment, thereby allowing engagement to occur.

Conversely, the present study failed to demonstrate a statistically significant association between the presence of LT displacement and fracture pattern, failing to support the hypothesis that the iliofemoral ligament plays a decisive role in determining fracture morphology. This represents a limitation of the current study, and further investigations are warranted to clarify these findings.

Interpretation/comparison with previous studies

The proportion of IT fractures in the elderly is increasing globally. For instance, in the United Kingdom, hip fractures

Table 4. The relationship between the combined anterior fracture line position and lesser trochanter (LT) displacement with the fracture pattern

Group	Medial+ intact	Medial+ displaced	Lateral+ intact	Lateral+ displaced	Total
Engaged	16	11	5	17	49
Completely displaced	3	2	10	12	27
Partially displaced	11	3	3	3	20

Omnibus test across all groups (3×2×2 contingency): χ^2=6.91, df=4, P=0.140 (not significant).
Within-group Fisher exact test (association between anterior fracture-line location and LT displacement): (a) Engaged group: P=0.047 (weak association between lateral fracture line and LT displacement). (b) Completely displaced group: P=1.000 (no association). (c) Partially displaced group: P=0.400 (no association).

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increased by 7% between 2020 and 2023 [10], whereas in Germany, hip fractures accounted for 22% of all fractures among elderly individuals in 2019 [11]. Mortality associated with these fractures remains high, with 5%–10% of patients dying within 1 month and 33% within 1 year. Furthermore, only approximately one-third of affected individuals regain their preinjury level of activity [12].

Early ambulation is crucial for achieving a favorable prognosis, with stable fixation serving as the primary determinant of early mobilization. Despite improvements in surgical techniques and implant designs, fixation failure continues to occur in 5%–20% of cases [13].

Understanding fracture morphology is essential for achieving successful fixation, with increasing emphasis on extramedullary reduction and anteromedial cortical support [14]. Existing IT fracture classifications are primarily morphology-based and do not account for displacement. These fractures can be further categorized into nondisplaced, engaged, and completely displaced types according to the degree of displacement.

While displaced types are known to result from factors such as iliopsoas muscle and external rotation, the mechanism underlying engaged-type fractures remains unclear until now. This study hypothesized that the joint capsule, pericapsular ligaments—particularly the iliofemoral ligament—and the iliopsoas tendon influence displacement patterns in IT fractures.

According to a previous study by Chandak et al. [15], it has been suggested that, in irreducible severe IT fractures, the iliopsoas tendon may influence both displacement and reduction. They reported that the distal end of the proximal fragment in an IT fracture can become entrapped by the iliopsoas tendon, thereby preventing closed reduction. This implies that the distal portion of the proximal fragment lies in very close proximity to the iliopsoas tendon. In the current study as well, among progressively displaced fractures, partially displaced cases with an intact lesser trochanter showed a clear predominance of fracture lines located medial to the IT line compared with those located laterally (Table 4). This finding may suggest a possible role of the capsular ligament and iliopsoas tendon in limiting further displacement of the fracture. It is hypothesized that these soft-tissue structures could help prevent complete separation while varus angulation of the proximal fragment leads to partial displacement into the medullary canal (Fig. 4). Conversely, in fractures with a similar pattern but with complete displacement, it can be assumed that rupture of the capsular ligament has occurred. Moreover, our results showed that completely displaced types were often located lateral to the IT line, that is, in extracapsular fractures, suggesting that the iliofemoral ligament and anterior capsule may contribute to fracture displacement.

Recently, the cephalomedullary nail has become the most preferred treatment method for IT fractures [16]. In most cases, cephalomedullary nails are inserted after closed reduction, which offers the advantages of relatively shorter operative time and reduced blood loss. During reduction, intramedullary reduction should be strictly avoided, and slight overcorrection to achieve extramedullary reduction is recommended whenever possible [7,8]. However, in engaged-type fractures where the capsular ligament remains attached to the distal fragment, obtaining anatomical reduction using the capsule and capsular ligament is not particularly difficult, but achieving overcorrection for extramedullary reduction can be technically very challenging. In such cases, based on the author's experience, performing open reduction with capsulotomy can facilitate extramedullary reduction. Therefore, it is important to evaluate the positional relationship between

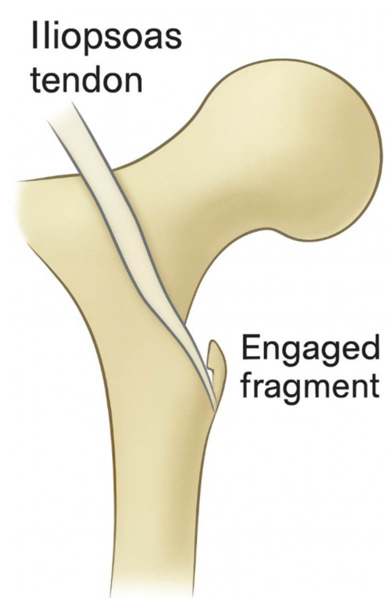

Fig. 4. Schematic illustration of the mechanism through which the iliopsoas tendon contributes to engagement of the proximal fragment.

the capsule, capsular ligament, and fracture line preoperatively to plan the surgical approach. Although magnetic resonance imaging (MRI) was not performed in this study, future research on engaged-type fractures should consider preoperative MRI to assess the condition of the capsular ligament.

Limitations

Our study has several limitations. First, the sample size was relatively small. In addition, because this study was designed to identify specific factors influencing fracture patterns, cases that were excessively unstable or severely comminuted, making it difficult to determine the origin or main fracture line, were excluded from the analysis. Finally, the absence of magnetic resonance imaging limited our ability to more strongly validate the proposed hypothesis. Future studies are planned to address these limitations.

Generalizability

Generalizability is primarily limited to adults aged 60 years and older with fragility IT fractures treated operatively in settings where preoperative 3D-CT and similar classification methods are utilized. External validity may be constrained by the inclusion of only two hospitals and a single-surgeon cohort, as well as by exclusions such as high-energy trauma, reverse oblique, undisplaced, or severely comminuted fractures.

Conclusions

Fracture lines lateral to the IT line were strongly associated with displacement in IT fractures; however, their relationship with LT involvement—representing iliopsoas tendon traction—was not clearly demonstrated. Although the factors influencing the engaged-type fracture remain inconclusive, the statistical association between fracture pattern and anterior fracture-line position suggests that the capsular structures may contribute to stability in select fracture configurations. Further studies are warranted to clarify these anatomical interactions.

Article Information

Author contributions

Conceptualization: JSC, CHK. Data curation: SOK, CHK. Formal analysis: JYP, CHK. Investigation: JYP, SOK. Supervision: JSC. Visualization: JYP, SOK. Writing-original draft: JSC, CHK. Writing-review & editing: all authors. 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

Contact the corresponding author for data availability.

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Supplementary materials

None.

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Computed tomography plane reformatting to reduce projection error in measuring Pauwels angle of femoral neck fractures: a cross-sectional study

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Objectives: This study aimed to assess fracture verticality in both coronal and axial planes after eliminating projection error in femoral neck fractures among non-older adults, and to demonstrate its clinical utility using computed tomography (CT)-based modeling at actual size.

Methods: This retrospective observational study enrolled 57 patients (30 males and 27 females), aged 20–65 years, with displaced femoral neck fractures. Based on CT images, an actual-size fracture model was constructed. The CT scanning plane was reformatted with the neck-shaft fragment realigned vertically to the ground and parallel to the femoral neck axis. Three consecutive images were used to generate coronal reformats at the centerline and posterior border to measure central and posterior coronal plane verticality as Pauwels angle (PA). The central image of the reformatted axial plane was used to assess axial plane verticality. Differences in verticality were analyzed using analysis of variance.

Results: Three coronal morphology types were identified: linear (n=30), concave (n=25), and convex (n=2). Two axial morphology types were observed: cephalad (n=35) and trochanteric (n=22). The mean central PA, posterior PA, and axial verticality were 55.43°±13.79°, 51.44°±11.13°, and 85.70°±18.42°, respectively. Only the central PA showed a significant difference (P<0.001). The PA was significantly higher in the linear coronal type between images (P<0.05) and in the trochanteric axial type (P<0.05).

Conclusions: After reformatting the scanning plane, the central PA showed significant variation between images. Femoral neck fractures of the linear type in the coronal plane and the trochanteric type in the axial plane demonstrated greater verticality than other morphological types.

Level of evidence: III.

Keywords: Femur; Femoral neck fractures; X-ray computed tomography; Analysis of variance

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Introduction

Background

Femoral neck fractures can be classified based on coronal verticality of fracture orientation and biomechanical properties as originally described by Pauwels in 1935

[1,2]. It is well known that vertically oriented femoral neck fracture (Pauwels' type III) should be distinguished since this fracture causes high-shear force and consequently there was a high rate of fixation problems, including nonunion and fixation failure [3-5]. Vertical neck fractures in non-older adults should be especially distinguished because different fixation strategies must be applied to optimize postoperative stability of the bone-implant interfaces against a high-shear force [6-10]. Considering that fracture types are originally dependent on coronal verticality (Pauwels angle, PA), PA measurement based on an exact method with a clear consensus is a prerequisite for classifying fractures and choosing optimal fixation constructs [7,8,11].

A previous study [11] has demonstrated that PAs are significantly different between the two measurement methods according to the computed tomography (CT) scanning plane. In the reformatted CT scan plane along the neck centerline to eliminate projection error, PAs increased in all cases, and showing a mean difference of 15.7° [11]. However, one of the shortcomings is that we used only one reformatted coronal image to measure the PA. Consequently, there was no morphologic consideration of isolated high-shear angle fractures, which had significant neck comminution (96%), located mainly in inferior and posterior quadrants in young adults [12]. Here, a clinical CT-based model of femoral neck fracture in non-older adults was developed to measure fracture verticality without projection angle through synchronized windows composed of images from the axial, coronal and sagittal planes.

Objectives

The primary objectives of this CT-based clinical study were (1) to assess the verticality of fracture in the reformatted coronal and axial planes without projection error; (2) to evaluate morphological features of femoral neck fracture; and (3) to introduce practical implications by analyzing the correlations.

Methods

Ethics statement

This study was approved by the Institutional Review Board (IRB) of Gyeongsang National University Changwon Hospital (IRB No. GNUCH 2019-04-014), and the requirement for informed consent was waived because it involved the retrospective analysis of the medical records and radiographs.

Study design

It is a cross-sectional study.

Setting

The study was performed at the Gyeongsang National University Changwon Hospital, in Changwon, Korea. Eligible cases were identified from the institutional electronic medical record (EMR) and picture archiving and communication system (PACS) between January 1, 2020 to December 31, 2020.

Participants

By reviewing the medical histories and radiographs obtained at the time of injury, a total of 153 patients with femoral neck fractures were screened, of whom 57 were finally enrolled. Patients were eligible if they were aged 20–65 years, had an acute femoral neck fracture confirmed on radiography/CT, and had preoperative CT available in Digital Imaging and Communications in Medicine (DICOM) format with slice thickness 2 or 3 mm. This study excluded patients over 65 years of age, those with concomitant lower extremity injuries (e.g., femur shaft fracture, femoral head dislocation and tibial fractures), patients with pathological fractures, and patients who had previously undergone surgical treatment of the same hip joint. Base fracture of the femoral neck (basicervical fracture) was also excluded through the closed radiographic review [13]. Finally, 57 patients (30 males and 27 females) were enrolled, and the mean age of the patients enrolled was 47.3±11.3 years old.

Variables

The primary outcome variable was a difference in central coronal verticality (central PA) across three consecutive central coronal images after standardized reformatting. Secondary outcome variables included differences between posterior coronal images (posterior PA) and axial images (axial verticality), and associations between verticality and morphology types.

Data sources and measurement

CT data of slices with a thickness of 2 or 3 mm in the format of DICOM were imported into Materialise Interactive Medical Image Control System (Mimics) software (Materialise) to reconstruct the femoral neck fracture model (fracture model) at actual size, which could be synchronized in coronal, sagittal and axial planes. To make consistent measurements and eliminate projection error, we applied the following steps using tools of Mimics software [11,14]: (1) The proximal femur was selected as a cropping area, the scanning plane was reformatted parallel to the neck midline of the neck-shaft fragment in the axial plane, and the proximal femur was realigned vertically to the ground in the coronal plane (Fig. 1). (2) To measure the coronal verticality, we selected three consecutive images from the neck midline to the posterior direction (central verticality [central PA]) and three consecutive images from the posterior border to the anterior direction (posterior verticality [posterior PA]) as coronal reformatted images. (3) The coronal PA of six coronal reformatted images was measured using the centerline of the proximal shaft (Y-axis) and the ground line (X-axis) as a constant guideline [15]. Among them, the greatest value was determined as maximum (max) central and max posterior PA (Fig. 2A). (4) For the axial verticality, the scanning plane was reoriented again parallel to the neck axis of the neck-shaft fragment both in axial and coronal plane (Fig. 2B). (5) We selected three consecutive images from center to inferior as the axial reformatted images. The axial verticality was defined as the angle between the centerline of femoral neck and the imaginary line between the anterior and posterior ends of the fracture. The greatest value was determined as the max axial verticality (Fig. 2B).

In the reformatted coronal images, the coronal PA was used to classify three types of Pauwels' (type I <30°, type II, 30°–50°, and III >50°). Based on the fracture line, the coronal morphology (coronal type) was divided into three types of linear, convex, and concave type (Fig. 3A). Concerning the axial morphology (axial type), if the angle of axial verticality was less than 90°, it was a cephalad type, and if it was more than 90°, it was a trochanteric type (Fig. 3B).

Bias

We attempted to reduce selection bias by including consecutive eligible patients with available CT during the study period. Residual bias may exist because CT acquisition may reflect local practice patterns and injury severity. Measurement bias was addressed by standardized CT plane reformatting and use of fixed reference axes; remaining bias may arise from manual landmark placement and fracture comminution.

Study size

The study size was determined by the number of eligible

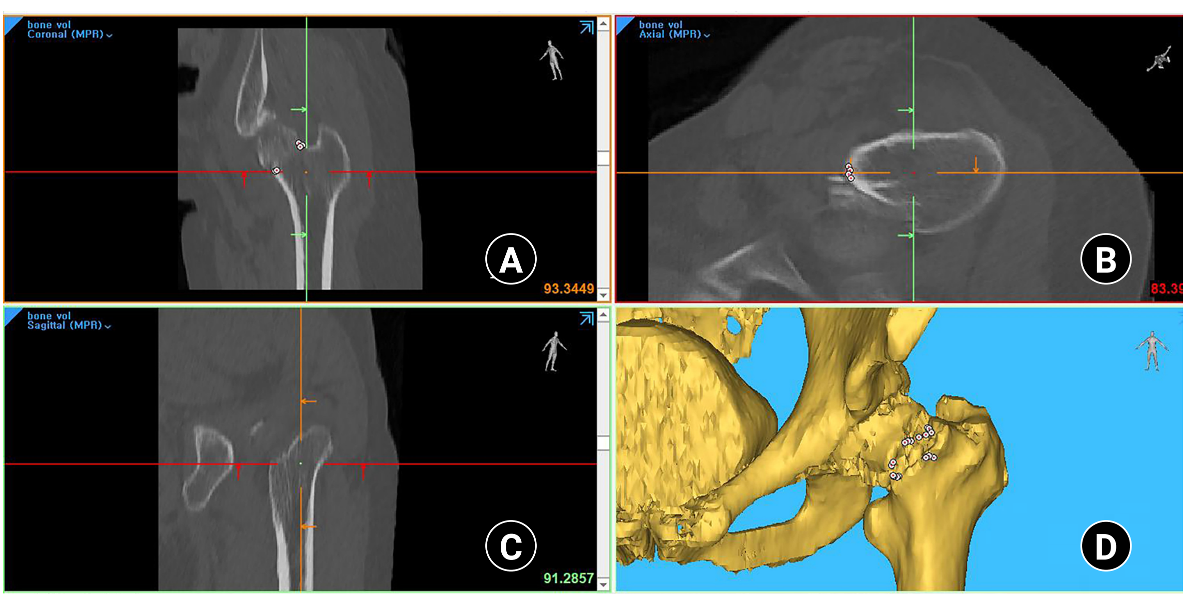

Fig. 1. After the proximal femur was selected as a cropping area, the scanning plane was reformatted parallel to the neck midline of the neck-shaft fragment in the axial plane. The proximal femur was then realigned vertically to the ground in the coronal plane using tools of Mimics software. Then, fracture morphologies were assessed in coronal (A), axial (B), sagittal (C), and three-dimensional biplanar plane (D).

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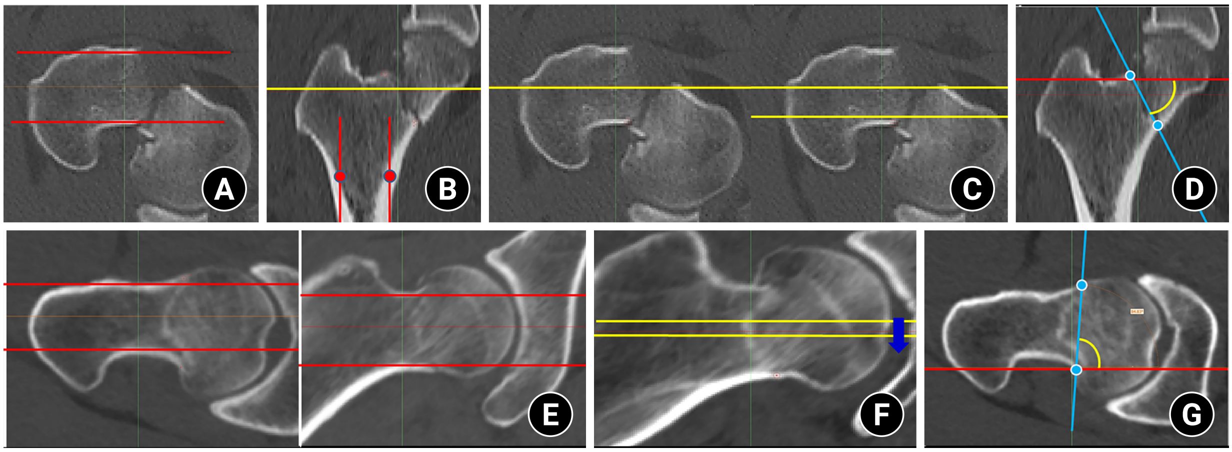

Fig. 2. To make consistent measurements and eliminate projection error, after the computed tomography scan plane was reformatted to an axial plane parallel to the femoral neck axis, red lines were placed anterior and posterior to the neck cortex in the axial (A) and coronal (B) planes. The yellow lines were placed in the centerline and posterior cortex (C). Then, (D) the coronal Pauwels angle (PA) was measured between the red line (ground line) and the blue line (reformatted fracture angle) in three consecutive images of the coronal plane. (E) The red line marked the anterior and posterior cortex in the axial and coronal planes. (F) The yellow lines were placed along the centerline of the neck, and three consecutive images of the axial plane were chosen. Then, (G) The axial PA was measured between the red line (ground line) and the blue line (reformatted fracture angle).

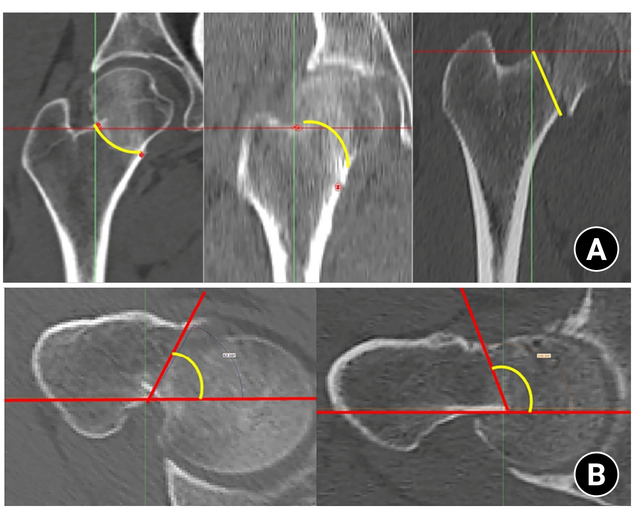

Fig. 3. (A) In the reformatted coronal images, fractures were classified into three morphological types—linear, convex, and concave—based on the fracture line. (B) Axial verticality was classified according to the measured angle: fractures with an angle <90° were defined as the cephalad type, and those with an angle ≥90° as the trochanteric type.

cases available during the predefined study period (n=57 included). Because this was a retrospective study, no prospective sample-size calculation was performed; the analysis was intended to estimate differences in within-fracture measurements and their associated precision.

Statistical methods

For ordinary scales, statistical evaluation was performed using the chi-square test. Continuous data from consecutive images were analyzed using repeated-measures analysis of variance followed by Bonferroni's post hoc test. Statistical significance was considered when the P-value was less than 0.05. The IBM SPSS ver. 29.0 (IBM Corp.) was used for all statistical analyses. There were no missing imaging outcomes.

Results

Coronal and axial verticality across consecutive reformatted images

All results of coronal and axial verticality are summarized in Table 1. Central PA values were 55.43°±13.79°, 53.40°±13.69°, and 53.08°±13.09° and posterior PA values were 51.44°±11.13°, 50.91°±11.75°, and 50.00°±11.42° for three consecutive images. The max central PA had a mean value of 56.42° (range, 30.1°-85.0°; SD, 13.46°) and the max posterior PA, 53.47° (range, 34.6°-79.2°; SD, 10.68°). The axial verticality values of three consecutive images were 85.70°±18.42°, 85.85°±18.55°, and 85.85°±19.23°, respectively (Fig. 4). The max axial verticality had a mean value of 87.64° (range, 44.5°-137.1°; SD 18.78°). Concerning the

Table 1. Overall characteristics and comparison of verticality

Verticality	Consecutive image			RM-ANOVA			Pairwise comparison	
	1st	2nd	3rd	F-ratio	P-value	Image	Mean difference	P-value
C-Co (°)	55.43±13.79	53.40±13.69	53.08±13.09	8.796	<0.001	1st vs. 2nd	2.033±0.546	0.001
	-	-	-	-	-	1st vs. 3rd	2.353±0.675	0.003
	-	-	-	-	-	2nd vs. 3rd	0.319±0.597	1.000
P-Co (°)	51.44±11.13	50.91±11.75	50.00±11.42	2.484	0.088	1st vs. 2nd	0.528±0.568	1.000
	-	-	-	-	-	1st vs. 3rd	1.435±0.815	0.252
	-	-	-	-	-	2nd vs. 3rd	0.907±0.534	0.285
Ax (°)	85.70±18.42	85.85±18.55	85.85±19.23	0.069	0.933	1st vs. 2nd	−0.151±0.326	1.000
	-	-	-	-	-	1st vs. 3rd	0.151±0.326	1.000
	-	-	-	-	-	2nd vs. 3rd	−0.002±0.433	1.000

Values are presented as mean±standard deviation.
RM-ANOVA, repeated-measures analysis of variance; C-Co, central coronal verticality (central PA); P-Co, posterior coronal verticality (posterior PA); Ax, axial verticality; PA, Pauwels angle.

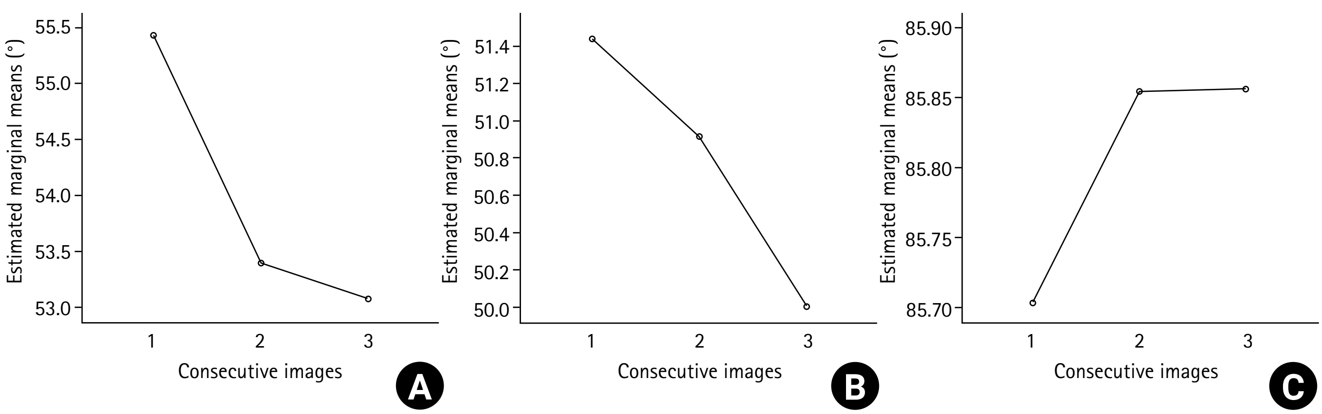

Fig. 4. Measured values of (A) central coronal verticality, (B) posterior coronal verticality, and (C) axial verticality demonstrating inter-image differences.

normality test, all coronal and axial verticality variables were satisfied (P>0.05). When comparing the max central and posterior PA, their mean difference was 2.94°±10.11°, which was statistically significant (P=0.032). The mean central PA differed statistically significantly among the three central images (F=8.796, P<0.001). The central PA decreased statistically significantly from the 1st central image to the 2nd image (2.033° [95% CI, 0.69-3.38], P<0.001), and from the 1st central image to the 3rd image (2.353° [95% CI, 0.69-4.02], P=0.003), but not from the 2nd image to the 3rd image (0.32° [95% CI, -1.16 to 1.79], P=1.000). The mean posterior PA was not significantly different among the three posterior images. An axial verticality was not significantly different (Table 1).

Coronal and axial fracture morphology classification

Concerning the fracture morphology in the coronal plane, it was a linear type for 30 cases (52.6%), a concave type for 25 cases (43.9%), and a convex type for two cases (3.5%). In the axial plane, there were 35 cases (61.4%) of the cephalad type and 22 cases (38.6%) of the trochanter type. Based on the max central PA, Pauwels' type II had 15 cases and Pauwels' type III, 39 cases. For the max posterior PA, Pauwels' type II had 22 cases, and Pauwels' type III 35 cases.

Verticality measures by morphology subtype

Depending on the fracture type, all results are summarized in Table 2. Concerning the correlation of PA and coronal type (55 cases, except two cases of convex type), the only central PA differed significantly between images (F (2,11)=9.541; P<0.001) (Fig. 5). Concerning the coronal

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Table 2. Overall results of Pauwels' classification and comparison of verticality and fracture types

Fracture type	Image of central coronal verticality				Image of posterior coronal verticality				Axial image			
	1st	2nd	3rd	P-value	1st	2nd	3rd	P-value	1st	2nd	3rd	P-value
Pauwels I	1	1				1	1					
Pauwels II	18	24	28		28	29	24					
Pauwels III	38	32	29		29	27	32					
Linear	59.18±14.03	56.61±14.46	56.37±13.54	<0.01	54.23±11.03	54.01±10.74	53.36±10.17	0.05	92.09±17.89	92.54±18.18	92.38±19.50	0.945
Concave	51.48±12.96	49.72±12.43	49.15±12.20		48.52±11.01	47.58±12.53	45.95±12.18		79.00±17.06	78.71±16.73	78.86±16.85	
Cephalad	52.32±11.53	50.82±11.85	50.81±11.08	<0.01	50.24±10.58	50.04±11.79	48.91±11.23	0.11				
Trochanter	60.38±15.81	57.50±15.61	56.69±15.37		53.36±11.97	52.31±11.81	51.74±11.77					

Values are presented as mean±standard deviation.

morphology, all verticality angles of the linear type were significantly higher in six coronal images and three axial images. For axial type, the central PA differed significantly between images (F (2.11)=10.116; P<0.001). However, the posterior PA was not significantly different (P=0.112). The coronal PA of the trochanteric type was significantly higher (P<0.001).

High-verticality subgroup analysis

Considering differences in verticality angle between reformatted images, fractures with a linear type in the coronal plane and trochanteric type in the axial plane were stratified as a high verticality group, and 11 femurs were included. The central PA of the high verticality group had a mean value of 58.07°±3.18°. For others, the mean was 52.22°±2.07°. The posterior PA of the high verticality group had a mean value of 52.54°±2.70°, and those of others had a mean value of 50.04°±1.76°. Only central PA differed significantly between groups (F (2,11)=10.472; P<0.001) (Table 3).

Discussion

Although Pauwels' biomechanical classification is in use nowadays, practical measurement of coronal verticality had lower reliability in preoperative radiographs due to projection errors and leg deformity during radiographic examination [11,16,17]. Considering that femoral neck fractures in non-older adults inevitably have significant displacement and comminution of fracture site, the conventional method to measure the PA is technically difficult in practice. Thus, we performed verticality measurements in multiple sites based on a previous study [11]. Through this imaging study, we would introduce how to apply Pauwels' classification in practice after eliminating projection error of comminuted neck fracture in non-older adults. By using the software to allow free 360° rotations with magnification in any plane, this study has several interesting and practical findings. First, among six coronal images, the centerline image had the highest value of coronal PA. The coronal PA of the 1st central image was a mean value of 55.43°±13.79° and the 1st posterior images, mean value of 51.44°±11.13 (P=0.003). Second, CT scanning planes along the centerline of the femoral neck in coronal and axial planes could be used to measure the maximal fracture verticality without specialized software or equipment (Fig. 6).

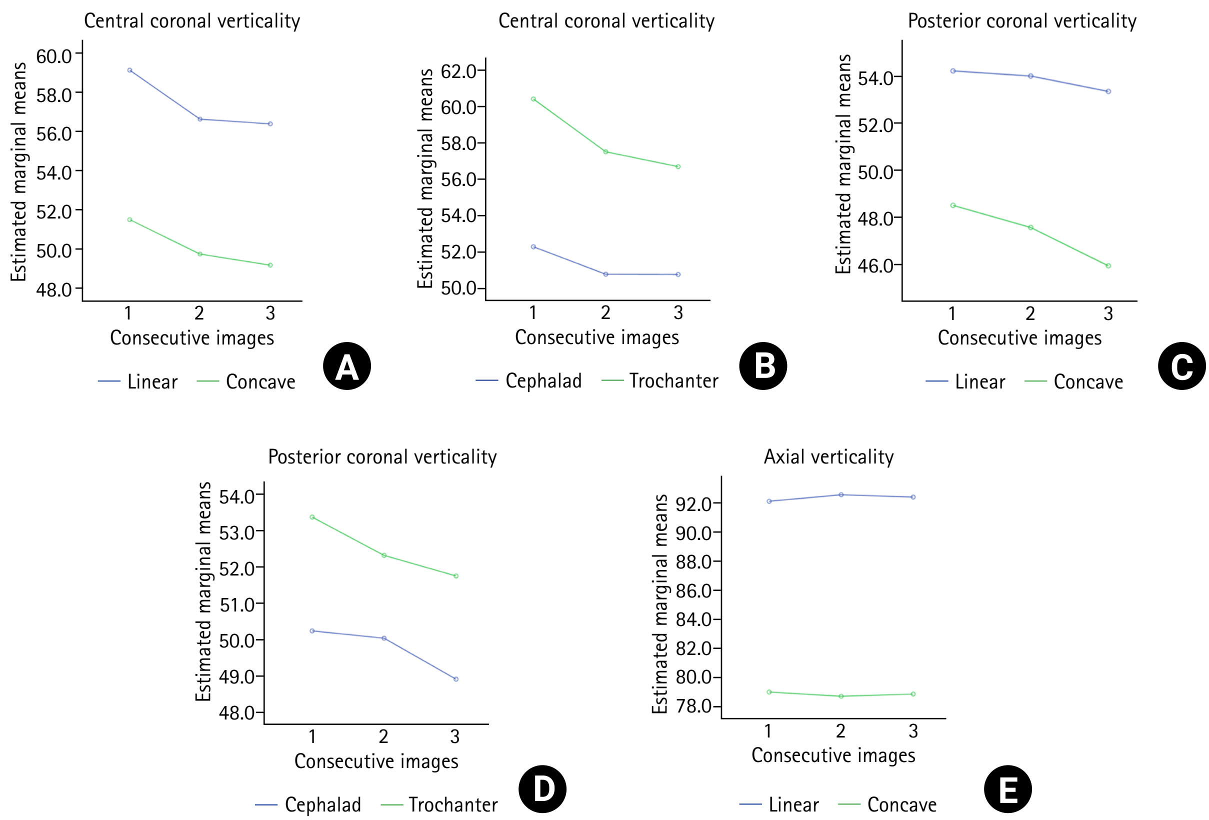

Fig. 5. The central coronal PAs were compared for linear vs concave fracture types (A) and cephalad vs trochanter types (B). The posterior coronal PAs were compared for linear vs. concave types (C) and cephalad vs. trochanter type (D). Axial verticality was compared between linear and concave types (E). Two-way repeated-measures analysis of variance showed that the only central coronal verticality differed significantly between images.

Table 3. Overall characteristics and comparison between the high verticality group and others

Verticality	Consecutive image		RM-ANOVA		Pairwise comparison	
	High verticality[a]	Others	F-ratio	P-value	Mean difference	P-value
C-Co (°)	58.07±3.18	52.22±2.07	10.47	<0.001	5.849±3.794	0.129
P-Co (°)	52.54±2.70	50.04±1.76		0.230	2.493±3.219	0.442

C-Co, central coronal verticality (central PA); P-Co, posterior coronal verticality (posterior PA); PA, Pauwels' angle; RM-ANOVA, repeated-measures analysis of variance;
[a]High verticality group of linear and trochanter type.

Third, fractures of the linear type in the coronal plane and trochanteric type in the axial type had higher verticality than other types. Thus, they were classified into the high verticality group.

Regarding verticality measurement using CT images instead of plain radiographs, choosing the right image is essential. Compared with posterior coronal images, central images had greater PA in most cases. Our study demonstrates that the most central reformatted coronal image (centerline images) is the best for measuring the max PA. According to Collinge et al. [12], vertical femoral neck fractures had the major comminution and mostly located in the inferior and posterior quadrants. Thus, the PA was inevitably greater in centerline images, similar to our study results. Furthermore, all PA of linear-type fractures were significantly higher in six coronal images and three axial images. For axial morphology, the PA of the trochanteric type was significantly higher in central coronal images.

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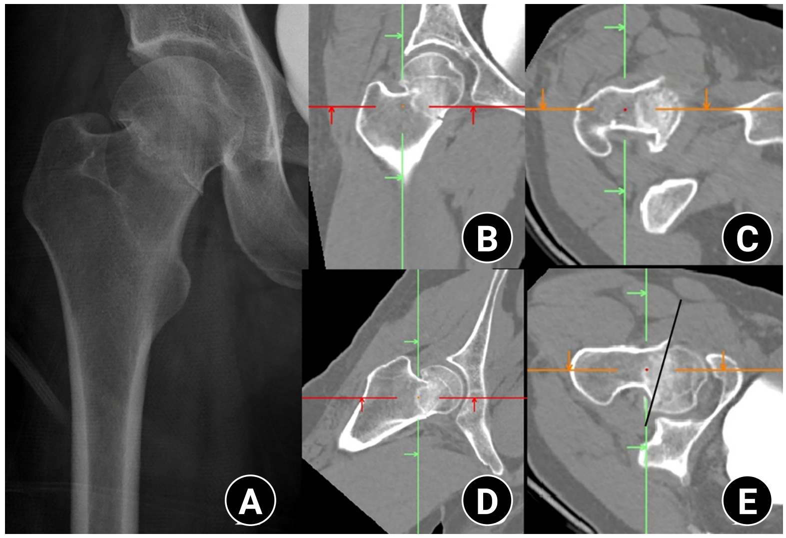

Fig. 6. A 38-year-old male patient presented with hip pain following a 3 m fall. (A) The initial plain radiograph revealed a femoral neck fracture. (B, C) The computed tomography (CT) plane parallel to the femoral neck centerline identified a convex fracture with a Pauwels angle of 45.1° in the coronal plane. (D, E) Reorientation of the CT plane along the femoral neck demonstrated a cephalad-type fracture with an axial verticality of 75.8° in the axial plane.

Based on our results, neck fracture of linear type in the coronal and trochanteric type in the axial plane could be classified into the high verticality group. Ideal images for measuring the PA are the centerline image in the coronal and axial plane. If the CT scanning plane is simply reformatted parallel to the neck midline of the neck-shaft fragment in the axial plane, centerline images will be readily available for measuring the PA without additional devices or support. Our simple and convenient method of reformatting the CT scan plane could be used for eliminating projection errors and accurately assessing the fracture morphology and PA.

Concerning the high risk of most vertical fractures leading to nonunion, fixation failure, and osteonecrosis, as already well known, they should be discriminated against to differentiate the fixation strategy [4,18,19]. However, although the practical measurement of PA had lower reliability, most vertical fractures were classified as Pauwels' type III and vertically oriented fractures. As mentioned above, the reformatted CT scan plane along the neck centerline could eliminate the projection error, and thus, the PAs were increased significantly [11]. Through the results of this study, the simple and convenient method of reformatting the CT scan plane, surgeons could stratify the high verticality group based on the fracture morphology and PA, which should be measured in the centerline image of the neck-shaft fragment. The femoral neck fracture of linear type in the coronal plane and trochanteric type in axial type is a higher verticality group.

Limitations

Despite our interesting findings, our computational measurement had several limitations. First, since the PA was measured manually using tools in Mimics software, there might be slight errors in measurement. Second, given the small sample size with only 57 enrolled fractures, our results might not be generalized. Third, clinical significance of the verticality difference according to the measurement method could not adequately be demonstrated because postoperative follow-up outcomes were not evaluated, and the clinical impact on surgical decision-making or fixation strategy was also unknown. However, our study's contribution lies in validating a widely used approach rather than proposing a novel method for measuring the PA (fracture verticality). After reformatting the CT scanning plane, the centerline coronal and axial images should be utilized to measure the PA and fracture verticality. Our CT scanning reformatted technique and findings allow us to easily differentiate a high verticality group from a neck fracture in non-older adults. This will help orthopedic surgeons decide on the best implants and anticipate clinical problems of fracture healing.

Conclusions

If the CT scanning plane is reformatted to be parallel to the neck and vertical to the ground, these images would be useful for eliminating projection errors and accurately assessing fracture morphology and verticality. Because central coronal and axial images had the highest PA, coronal and axial verticality should be measured in the centerline of the femoral neck. Concerning morphologic features, neck fractures of linear and trochanteric type had the highest angles. Thus, they were classified into the high verticality group. Our simple and convenient method of reformatting the CT scan plane is readily available to most surgeons without additional devices or support.

Article Information

Author contributions

Methodology: JYL. Investigation: JYL, SLJ. Visualization: GHJ. Writing-original draft: GHJ. Writing-review & editing: GMK, JYL, SLJ, 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

Contact the corresponding author for data availability.

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Supplementary materials

None.

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Hook plate fixation for volar plate avulsion fractures of the middle phalanges in Korea: a case series

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Background: Volar plate avulsion fractures in phalanges are relatively common injuries. While surgical treatment can help reduce limitations in motion after injury, the small size of the fracture fragment can make the procedure challenging. In this study, we used hook plate fixation as a surgical technique for treating volar avulsion fractures in phalanges and evaluated its radiological and clinical outcomes.
Methods: The medical records of eight patients (nine digits) with volar plate avulsion fractures of the middle phalanx were retrospectively reviewed. All fractures were treated with a 1.5-mm hook plate after open reduction. Radiologic evaluations were performed using simple radiographs, and clinical outcomes were assessed through range of motion, instability, and pain.
Results: The mean follow-up period was 4.9 months (range, 1–9 months). All nine digits achieved bone union at the final follow-up. The mean union time was 2.2 months (range, 1–4 months). In all patients, the range of motion in the proximal interphalangeal joint was 85° (range, 70°–100°) before implant removal and 89.4° (range, 80°–100°) after implant removal. All patients demonstrated no joint instability and no residual pain.
Conclusions: Using a hook plate for volar plate avulsion fractures presents a promising alternative to existing fixation methods. Its biomechanical advantages and ease of fabrication make it a valuable tool in hand surgery.
Level of evidence: IV.

Keywords: Fingers; Fracture fixation; Bone plate; Range of motion; Follow-up study

Original Article

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Introduction

Background

Volar plate avulsion fractures of the proximal interphalangeal (PIP) joint are relatively common injuries caused by hyperextension or axial loading, frequently observed in athletes and younger individuals engaged in contact sports [1,2]. Although many of these injuries can be managed conservatively, unstable fractures involving larger fragments or joint subluxation often require surgical fixation to restore joint congruity and prevent long-term stiffness, chronic pain, and functional impairment [3].

Several surgical techniques have been introduced, including tension band wiring, screw fixation, mini-plates, and suture anchor methods [4-6]. However, fixation of small or comminuted fragments remains technically demanding, and inadequate fixation may lead to loss of reduction or limited range of motion (ROM) [7,8]. Recently, hook plates have been proposed as an alternative fixation method that can effectively convert tensile forces of the volar plate into compressive forces across the fracture site, ensuring rigid fixation even in small fragment cases [3,4]

Objectives

This study aimed to evaluate the surgical outcomes of volar plate avulsion fractures by retrospectively reviewing the medical records. The findings will provide valuable insights into the surgical management of volar plate avulsion fractures, specifically focusing on the utilization of hook plates. This study can guide clinical decision-making and improve patient outcomes in the treatment of volar plate avulsion fractures.

Methods

Ethics statement

We conducted this study in compliance with the principles of the Declaration of Helsinki. This study was approved by the Institutional Review Board (IRB) Committees of the Medical Research Institute of Kyungpook National University Hospital (IRB No. KNUH 2023-05-035) and Samsung Changwon Hospital, Sungkyunkwan University School of Medicine (IRB No. SCMC 2023-05-016).

Study design and setting

This study is a case series. The medical records of patients in two centers who underwent open reduction and internal fixation using a hook plate at the phalanx from 2013 to 2020 were retrospectively reviewed.

The surgical indication for using the hook plate technique is displaced volar avulsion fracture of the phalangeal bones, which cause instability or extension lag. A large fragment with ROM limitation is also a surgical indication.

The surgical procedure was similar to that described by Kang et al. [3] and Thirumalai et al. [4]. All procedures were performed under general or regional anesthesia. A volar Bruner or zigzag incision was made to expose the PIP joint. The flexor tendon was retracted, and the volar plate was identified between the flexor tendons and the collateral ligament. The fracture fragment was visualized and meticulous dissection was performed to preserve soft-tissue attachments and vascularity. The hook plate was fabricated from a 1.5-mm modular hand system titanium plate (Synthes). A two- or three-hole plate was modified into a hook plate depending on the requirement. The cut ends of the plate were bent into hooks (Fig. 1). Anatomical reduction of the fracture fragment was successfully achieved using the hook plates (Fig. 2). Subsequently, the hooks were passed through these slips around the edge of the joint at the distal

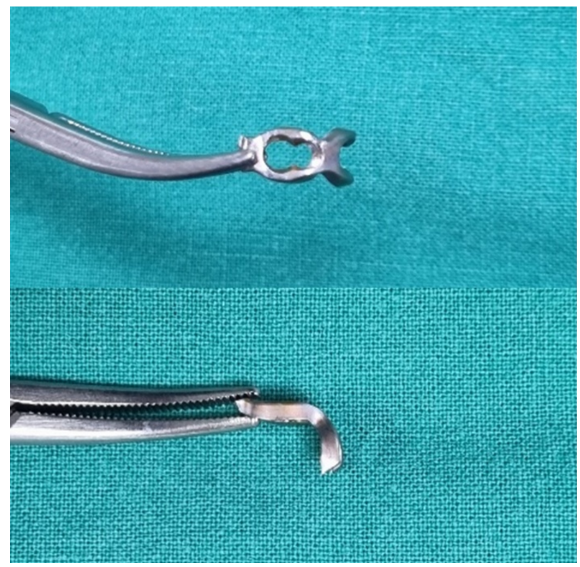

Fig. 1. Fabrication of a hook plate by bending the cut ends of a standard 1.5-mm modular hand system titanium plate into a hook shape.

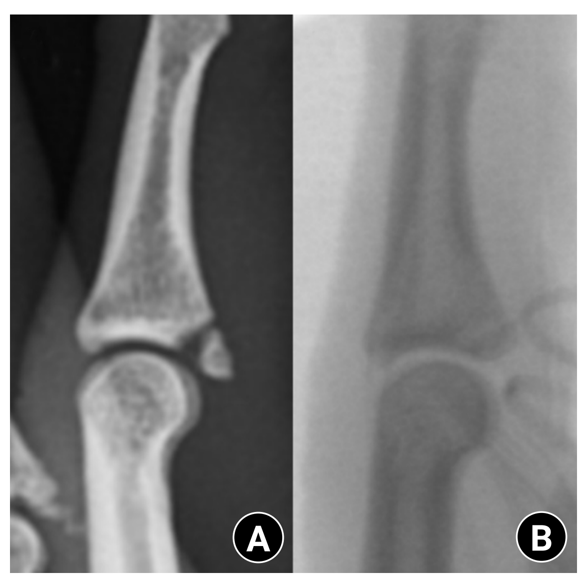

Fig. 2. Radiographs of a middle phalanx avulsion fracture. (A) Initial fracture. (B) Reduction after open reduction.

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edge of the fracture fragment. They grabbed onto the lip of the articular surface in an area that does not interfere with joint function. Then, the hooks were used to control and reduce the fracture fragment. A 0.9-mm K-wire could be used to help reduce and hold the fracture fragment temporarily while applying the plate. The plate crossed the fracture line and was fixed with a single screw distal to the fracture (Fig. 3). Fixation stability was confirmed by passively moving the joint through a full passive ROM under C-arm fluoroscopy. After surgery, the finger was immobilized in a functional position using a dorsal blocking splint for one week. Gradual active and passive ROM exercises were initiated thereafter under protective splinting, and unrestricted use was permitted after radiographic confirmation of bone union.

Once both clinical and radiographic union were confirmed, implant removal was recommended. Implant removal was routinely performed after confirming bone union, and the removal timing was considered equivalent to the time of union. Removal was recommended for all patients, but one patient declined secondary surgery. After bone union was achieved, the plate was removed (Fig. 4).

Participants

Patients with avulsion fracture at the middle phalanx were included. After excluding patients with dorsal and lateral avulsion fractures, nine volar plate avulsion fractures in eight patients were included. Inclusion criteria were displaced volar avulsion fractures of the middle phalanx with clinical instability or motion limitation. Exclusion criteria included dorsal or lateral avulsion fractures, comminuted fractures unsuitable for fixation, and incomplete medical records or follow-up.

Variables

The primary outcomes were radiographic/clinical bone union after hook plate fixation. The secondary clinical outcomes were active ROM of the PIP joint and PIP joint stability.

Data sources and measurement

Demographic and clinical data were abstracted from electronic medical records and operative notes. The clinical results were assessed by evaluating joint instability, residual pain, and changes in ROM before and after plate removal. Radiologic results including fixation failure and achievement of bone union were assessed using simple radiographs.

The criteria for bone union were defined as the disappearance of the fracture line and trabecular bridging across the fracture site on radiographs, accompanied by the absence of tenderness or pain at the fracture site during ac-

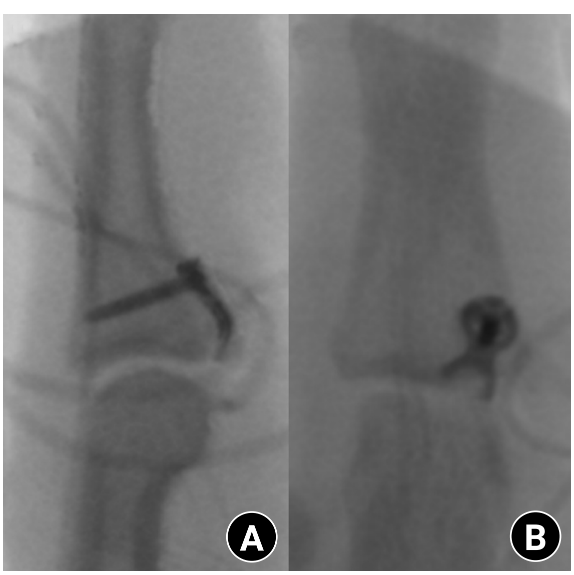

Fig. 3. Radiographs after hook plate fixation. (A) Lateral view. (B) Anteroposterior view showing the hook plate crossing the fracture line and secured with a distal screw.

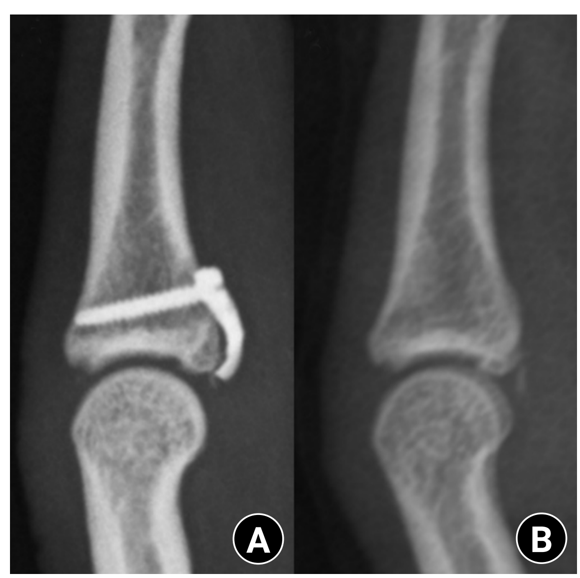

Fig. 4. Radiographs during follow-up. (A) Bone union after treatment with the hook plate. (B) Appearance after implant removal.

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tive motion.

Active ROM of the PIP joint was measured using a standard finger goniometer. Because this was a two-center study, ROM was assessed by two orthopedic surgeons (one at each institution) who followed a standardized measurement protocol and maintained close communication to minimize interobserver variability. ROM was measured twice for each patient—once at the final follow-up before implant removal and again at the follow-up visit after implant removal. As follow-up intervals varied among patients, this variability was acknowledged as a study limitation.

Bias

To minimize selection bias, consecutive patients who met the inclusion criteria were enrolled from both institutions. All surgeries were performed by two senior hand surgeons using a consistent surgical and postoperative rehabilitation protocol. ROM measurements were conducted by each surgeon at their respective institution, following a standardized protocol and maintaining close communication to reduce interobserver variability.

Study size

No a priori sample-size calculation was performed because this was an exploratory retrospective case series of a relatively uncommon surgical indication. All eligible subjects were selected.

Statistical methods

Analyses were primarily descriptive. Continuous variables were summarized as mean (range).

Results

Participants' characteristics and injury profile

The patients included five men and three women with a mean age of 27.2 years (range, 12–44 years). They had various injury mechanisms, including sports activity, assault, and industrial accident. The average time from the injury to the operation was 16.2 days (range, 1–90 days). The average duration of follow-up was 4.9 months (range, 1–9 months). All patients achieved union at final follow-up without fixation failure. The average time to union was 2.2 months (range, 1–4 months) (Table 1).

Outcomes after implant removal

Among the nine digits that achieved union, eight digits underwent implant removal. After implant removal, no complications were observed, and the joints had good stability and showed slightly increased ROM. In all patients, the ROM in the PIP joint was 85° (range, 70°–100°) before implant removal and 89.4° (range, 80°–100°) after implant removal. The mean postoperative interval of ROM measurement was 2.2 months before implant removal, corresponding to the time of bone union, and 4.9 months (range, 1–9 months) at the final follow-up after removal. Because the timing of follow-up visits varied among patients, these measurements may not represent identical postoperative stages for all cases. All patients exhibited no joint instability and no residual pain.

Discussion

Key results

After hook plate fixation for middle phalanx volar plate avulsion fractures, all digits achieved bone union without fixation failure. The mean time to union was 2.2 months (range, 1–4 months). Eight digits underwent implant removal, with no complications related to the removal. The average active ROM of the PIP joint was 85° before removal and 89.4° after. At the final follow-up (mean, 4.9 months), no patients exhibited joint instability or residual pain.

Interpretation and comparison with previous studies

This study demonstrated that hook plate fixation provided consistent bone union and favorable joint stability, even in small avulsion fragments. The surgical management of volar plate avulsion fractures poses significant challenges

Table 1. Baseline demographic and clinical outcomes (patients=8, digits=9)

Variable	Value
Age (yr)	27.2 (12–44)
Sex (male:female)	5:3
Injury-to-surgery interval (day)	16.2 (1–90)
Follow-up duration (mo)	4.9 (1–9)
Time to union (mo)	2.2 (1–4)
ROM at PIP joint before removal (°)	85 (70–100)
ROM at PIP joint after removal (°)	89.4 (80–100)

Values are presented as mean (range).
ROM, range of motion; PIP, proximal interphalangeal.

due to the fixation of small fragments and the restoration of joint stability. For fragments of large size, fixation options such as mini screws and pull-out sutures are available and have been reported to yield good results [9]. However, for smaller fracture sizes, the options for achieving stability through fixation are limited, leading to a greater consideration of conservative treatment. Additionally, fragment excision has been reported as a method to reduce limited motion following conservative treatment [10,11]. This retrospective study aimed to evaluate the surgical outcomes of volar plate avulsion fractures using hook plates as the primary treatment modality.

Hook plates represent an excellent option for overcoming these issues. Since being reported by Teoh and Lee [12] as a method for fixing bony mallet fragments at the base of the distal phalanx, hook plates have been developed and refined. They offer the advantages of being small in size, minimizing joint invasion, and being easy to manipulate. Although only a single screw was used for distal fixation, the hook component effectively acted as a tension band converting tensile forces into compression across the fracture site, providing sufficient stability even for small fragments. Additionally, it does not directly penetrate the fracture fragments for fixation, thereby reducing the risk of fragment comminution. In addition to avoiding fragment comminution, this technique minimizes soft-tissue disruption and preserves the biological environment around the fracture site, which may facilitate bone healing and reduce postoperative adhesion.

Teoh and Lee [12] reported successful fixation of distal phalanx mallet fractures without adhesion or joint stiffness, while Kang et al. [3] later applied the hook plate to proximal phalangeal base fractures and observed occasional tendon adhesion and stiffness. In contrast, our study applied hook plate fixation to middle phalanx volar plate avulsion fractures, achieving complete union and no adhesion, likely due to minimal volar dissection and timely implant removal. Our findings demonstrate that the utilization of hook plates for the fixation of volar avulsion fractures resulted in successful bone union in all patients, with an average union time of 2.2 months. Before and after implant removal, the ROM of the PIP joint increased from 85 degrees to 89.4°, which is consistent with that in previous studies.

There are certainly disadvantages to using hook plates, such as potential irritation or adhesion caused by the implant [3]. However, in our study, these complications were not observed, possibly prevented by the removal of implants in eight out of nine digits, suggesting that implant removal may have contributed to avoiding such complications.

In our study, implant removal was performed in eight out of nine digits. Following implant removal, good joint stability and a slight increase in the ROM of the PIP joint were observed. No additional manipulation such as brisement was performed at the time of implant removal, and the improvement in ROM occurred gradually during postoperative rehabilitation rather than immediately after removal. This improvement in ROM indicates successful fracture healing and postoperative recovery. Although plate removal after bone union still remains controversial, we experienced limitation of joint motion and restoration of total ROM after removal in all patients. Additionally, plate removal can prevent potential tendon adhesion and joint stiffness that may be caused by the plate. We believe that implant removal should be performed promptly after bone union has been confirmed to prevent adhesion and facilitate early recovery of motion. We proposed that the plate should be removed after bone union to gain complete ROM.

The surgical technique used in this study, which is similar to that of Kang et al. [3] and Thirumalai et al. [4], allowed for the anatomical reduction of the fracture fragments and precise placement of the hook plate. The hook plate, which was fabricated from a 1.5-mm modular hand system titanium plate, provided the necessary stability by converting tensile forces into compressive forces across the fracture site.

Limitations

This study has several limitations to consider. Its retrospective design and small sample size limit the generalizability of the results. The relatively short follow-up duration also precluded assessment of long-term functional outcomes or degenerative changes. In addition, the timing of ROM measurement before and after implant removal was not completely standardized. Although the preremoval measurement was performed at the time of bone union (approximately 2.2 months postoperatively), the post-removal measurement corresponded to the final follow-up period

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(mean, 4.9 months; range, 1–9 months). Therefore, the observed improvement in ROM may partially reflect natural recovery over time rather than the direct effect of implant removal. Further prospective, comparative studies with larger cohorts are warranted to validate the long-term efficacy and safety of hook plate fixation for volar plate avulsion fractures.

Conclusions

The utilization of hook plates for the surgical treatment of volar plate avulsion fractures resulted in successful bone union and improved joint stability. The use of hook plates offers a viable treatment option for these challenging fractures, allowing for anatomical reduction and restoration of joint function. Further studies are needed to determine the long-term outcomes and compare the effectiveness of different surgical techniques in the management of volar plate avulsion fractures.

Article Information

Author contributions

Conceptualization: HJL, DHK. Data curation: KSL, SWS, HJK. Formal analysis: KSL, SWS, HJK. Funding acquisition: HJL. Investigation: KSL, SWS. Methodology: KSL, SWS, DHK. Project administration: DHK. Visualization: KSL, HJK. Writing-original draft: KSL, HJL, DHK. Writing-review & editing: all authors. 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

Contact the corresponding author for data availability.

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Supplementary materials

None.

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Surgical outcomes of the coracoid process fracture associated with the acromioclavicular joint injury in Korea: a case series

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Background: Excluding technical reports and isolated case reports, there are no published studies evaluating coracoid process fixation with or without an acromioclavicular joint (ACJ) stabilization procedure for coracoid process fractures associated with ACJ injury. The purpose of this study was to assess the surgical outcomes of coracoid process fractures associated with ACJ injuries and to determine the usefulness of coracoid process fixation with or without an ACJ stabilization procedure.

Methods: From February 2006 to December 2015, patients with coracoid process fractures associated with ACJ injuries were enrolled. Radiological and clinical outcomes were analyzed in 12 patients who underwent coracoid process fixation with or without an ACJ stabilization procedure. A 3.5 mm cannulated screw with a washer or a 3.0 mm headless compression screw was used for coracoid process fixation, and either a clavicle hook plate or Kirschner (K)-wires were used for ACJ injuries when additional fixation was necessary.

Results: Bone union was achieved in 11 patients (91.7%), while one case was determined to be a nonunion at 6 months. Radiological union occurred at an average of 3 months (range, 1.5–4 months) in all patients except the nonunion case. At the final follow-up, the average clinical scores were a visual analogue scale pain score of 1.5 (range, 0–4) and a University of California, Los Angeles score of 30.9 (range, 28–35). Clinical outcomes were satisfactory in all patients, including the patient with nonunion.

Conclusions: The clinical and radiological outcomes of treating coracoid process fractures associated with ACJ injuries using coracoid process fixation with or without ACJ stabilization were favorable. A cannulated screw with a washer and clavicle hook plate fixation may provide sufficient stability for both the coracoid process fracture and the ACJ injury when feasible.

Level of evidence: IV.

Keywords: Shoulder; Acromioclavicular joint; Joint dislocations; Shoulder fractures; Coracoid process

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Introduction

Background

Scapular fractures accounted for only 1% of all fractures, and coracoid process fractures were relatively rare, accounting for approximately 6% to 8.2% of all scapular fractures [1,2]. Coracoid fractures and ipsilateral shoulder injuries often occur concurrently. Ogawa et al. [3] reported that 21.3% (17 of 80 cases) of coracoid fractures were accompanied by acromioclavicular joint (ACJ) dislocation. The concomitant coracoid fracture and ACJ injury indicated a double disruption to the upper shoulder support complex (SSSC). Goss [4] suggested that if the displacement is unacceptable, surgical reduction and stabilization of one or more of the injury site may be necessary. Ogawa et al. [5] showed that symptoms were present in 45% of coracoid nonunions, but most of these symptoms were insignificant. They suggested that coracoid nonunion itself is frequently asymptomatic, and that even if coracoid nonunion remains, satisfactory results can be achieved simply by treating the concurrent injury. Wignadasan et al. [6] reported that the clavicle hook plate could be safely used to treat double disruption of the SSSC in the form of concomitant coracoid base fracture and ACJ dislocation. Ye et al. [7] showed that fixation using a clavicle hook plate was a feasible treatment for coracoid fractures with ACJ dislocation and that satisfactory results were obtained. However, they reported a nonunion rate of 16.7% (3 of 18 cases) in coracoid process fractures, suggesting that the healing of coracoid process fractures may be related to the fracture morphology.

Kim et al. [8] introduced a technical report of coracoid process fixation using a cannulated screw without acromioclavicular fixation in cases of displaced fracture of the coracoid process associated with ACJ dislocation, using an open approach to the coracoid process and coracoclavicular ligament under fluoroscopic guidance. Bhatia [9] presented a technical report on percutaneous cannulated screw fixation and stabilization of coracoid base fracture associated with ACJ dislocation using coracoid fixation via indirect ACJ reduction under fluoroscopic guidance. To the best of our knowledge, no studies, excluding technical and case reports, have reported on coracoid process fixation with or without ACJ stabilization procedure in coracoid process fractures associated with ACJ injury.

Objectives

The purpose of this study was to evaluate the surgical outcomes of the coracoid process fracture associated with ACJ injury and to determine the usefulness of coracoid process fixation with or without ACJ stabilization procedure.

Methods

Ethics statement

This study was approved by the Institutional Review Board (IRB) of Daegu Fatima Hospital (IRB No. 2025-10-001), and the requirement for informed consent was waived.

Study design and setting

This study was a retrospective single-center case series evaluating surgically treated coracoid process fractures associated with ACJ injury. We reviewed medical records and imaging studies to describe radiologic union, clinical outcomes, and postoperative complications after coracoid fixation with or without ACJ stabilization at Daegu Fatima Hospital (Daegu, Korea) among those treated between February 2006 and December 2015.

Surgical technique

With the patient in the beach-chair position under general anesthesia, an oblique incision was made along Langer's lines between the coracoid process and the ACJ. Under C-arm fluoroscopic guidance, the lateral end of the clavicle was gently depressed to restore the AC joint alignment, and temporary fixation was achieved with a Kirschner (K)-wire. This maneuver reduced the tensile force transmitted through the coracoclavicular ligament, thereby allowing adequate compression during coracoid screw fixation.

After palpating the coracoid process, a guidewire was advanced through the fracture site toward the glenoid under orthogonal biplanar fluoroscopic control, following the technique described by Bhatia [9]. Once the position and depth of the guidewire were confirmed, a 3.5 mm partially threaded cannulated screw with a washer or a 3.0 mm headless compression screw (HCS; DePuy Synthes) was inserted along the guidewire. When sufficient compression and fixation stability were achieved and the ACJ reduction appeared satisfactory, the wound was closed.

In cases with minimal preoperative ACJ displacement, the temporary K-wire was removed before closure. However, when residual instability remained, the K-wire was left in situ with its tip exposed outside the skin, and the wound was sutured around it.

If adequate compression could not be achieved with screw fixation alone, the ACJ was first stabilized with a locking compression hook plate (clavicle hook plate; DePuy

Synthes). After sufficient relaxation of the coracoclavicular ligament was ensured, screw fixation was repeated to obtain firm compression at the fracture site. Postoperative radiographs were obtained to assess fracture reduction and fixation (Fig. 1).

Rehabilitation

After the surgery, a Kenny-Howard brace was used for a duration of 6 weeks. During the second week post-surgery, patients began gentle passive forward flexion arm exercises. At 6 weeks, patients initiated passive range of motion exercises in all directions, as well as active mobilization. Patients were prohibited from carrying heavy objects for three postoperative months.

Participants (patient selection)

We retrospectively studied the records of 12 patients with coracoid process fractures associated with ACJ injury who underwent coracoid process fixation with or without ACJ stabilization procedure and could be followed up for more than 6 months. The surgical indications were coracoid process fractures associated with ACJ injury as observed in either simple radiography or three-dimensional computed tomography (CT). All fractures were evaluated with

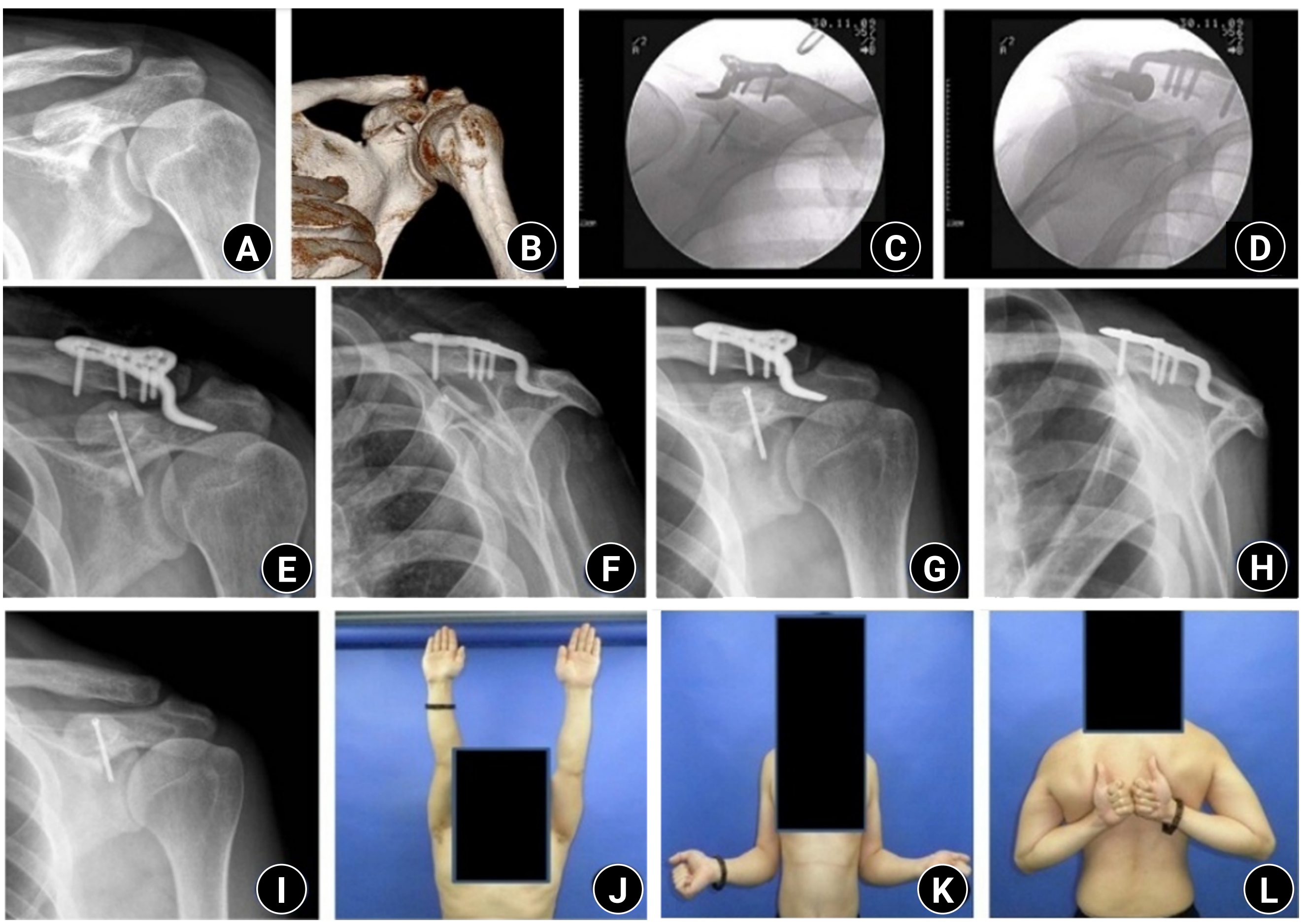

Fig. 1. (A, B) Initial shoulder anteroposterior (AP) radiograph and three-dimensional computed tomography images of a 33-year-old male patient show a coracoid process fracture associated with an acromioclavicular joint (ACJ) injury. (C, D) Immediate postoperative C-arm images demonstrate open reduction and internal fixation using a 3.0-mm headless compression screw (HCS) for the coracoid process fracture and a clavicle hook plate for the ACJ injury. (E, F) Immediate postoperative shoulder AP and scapular Y radiographs show fixation using a 3.0-mm HCS for the coracoid process and a clavicle hook plate for the ACJ injury. (G, H) Postoperative 2-month AP and scapular Y radiographs show union of the coracoid process. (I–L) At the final follow-up, the patient demonstrated satisfactory radiographic and clinical outcomes, including full active range of motion.

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the anteroposterior (AP), Grashey and scapular Y view throughout the follow-up period. ACJ injury was evaluated using simple radiography according to Tossy classification [10]. All patients underwent CT scans to assess the pattern of fracture of the coracoid process according to Ogawa and Eyres classification [11,12]. Exclusion criteria encompassed (1) individuals without a minimum 6-month follow-up post-surgery, (2) those with a prior history of shoulder surgery, (3) participants with additional injuries necessitating separate surgical interventions, (4) individuals experiencing neurovascular injuries preoperatively, and (5) patients with preexisting (chronic) coracoid process nonunion.

Variables

The primary outcome was the radiographic union of the coracoid fracture. Secondary outcomes included time to union, visual analogue scale (VAS) pain score at final follow-up, University of California, Los Angeles (UCLA) shoulder score at final follow-up, device-related complications, and the need for and timing of implant removal. Baseline variables included age, sex, affected side, injury mechanism, associated injuries, and fracture/ACJ classifications (Tossy, Ogawa, Eyres).

Data sources/measurement

In this study, union was determined as the point when cortical continuity was observed on one of the three planes of plain radiography (anteroposterior, Grashey, or scapular Y view), and when tenderness at the fracture site subsided. Coracoid fracture nonunion was defined as a fracture that had not united or mostly disconnected more than 6 months after surgery [6,7]. For all surgically treated patients, follow-up imaging was conducted at least up to 6 months postoperatively, with evaluations scheduled at 1, 2, 3, and 6-month intervals. Clinical outcomes were assessed based on the degree of pain and the restoration of daily functional activities. At the final follow-up, the following clinical outcome parameters were evaluated: VAS score and the shoulder rating scale of the UCLA score. Postoperative complications were also carefully assessed.

Bias

To reduce selection bias, we included all eligible patients during the study period who met the minimum follow-up criterion of six months. Measurement bias was minimized by using standardized radiographic views and predefined union criteria. Because fixation devices and ACJ stabilization were selected based on intraoperative stability and/or fracture characteristics, confounding by indication is possible; therefore, the results are reported descriptively without causal inference.

Study size

No sample size estimation was done because coracoid process fractures associated with ACJ injuries are rare; therefore, we included all eligible surgically treated cases during the study period.

Statistical methods

Given the small sample size and noncomparative design, the analyses were primarily descriptive.

Results

Participants' characteristics

A total of 12 patients with coracoid process fracture associated with the ACJ injury underwent open reduction and internal fixation using 3.5 mm cannulated screw with washer or 3.0 mm HCS. The average age of the patients was 51 years (range, 19-74 years), and the average follow-up period was 15.7 months (range, 6-70 months). Among the patients, 11 were men and one was a woman. The right and left sides were equal.

Injury characteristics and fracture/ACJ classification

The fractures occurred due to various mechanisms, including simple falls, sports injury, motor vehicle accidents, being hit by a heavy object, and falls from height. Six patients had accompanying multiple rib fractures, and four of them had a hemopneumothorax. According to Tossy's classification [10] of ACJ injuries, there were five cases of type 2 and seven cases of type 3. According to Ogawa's classification [11] for coracoid process fracture, all cases were type 1, but according to Eyres' classification [12], there were four cases of type 3, five cases of type 4, and three cases of type 5 (Table 1).

Radiologic union and clinical outcomes

Radiological union was achieved at a mean of 3 months (range, 1.5-4 months) in all patients except one case. The time to removal of K-wire fixation for ACJ injuries was 1.7 months (range, 1.5–2 months) and for clavicle hook plates it was 5.9 months (range, 3–7.5 months), with K-wire removal occurring earlier. At the final follow-up, the average clinical scores were as follows: a VAS for pain of 1.5 (range, 0-4) and a UCLA score of 30.9 (range, 28–35). Clinical outcomes in all patients were satisfactory [13] (Table 2).

Postoperative complications and implant removal

No postoperative infections or neurovascular complications were observed in any of the patients. However, one patient experienced nonunion. The K-wire for ACJ fixation was removed at 6 weeks after the operation, and nonunion of the coracoid fixation was confirmed at the final follow-up of 6 months, but the patient's clinical outcome was good (Fig. 2).

Discussion

Key results

Coracoid fractures resulted from various mechanisms. Six patients had multiple rib fractures, and four had hemopneumothorax. ACJ injuries were classified as Tossy type II (n=5) or type III (n=7). All coracoid fractures were

Table 1. Summary of demographic data

Patient no.	Age (yr)	Sex	Affected side	Injury mechanism	Classification			Combined injury	Follow-up (mo)
					Tossy type	Ogawa type	Eyres type		
1	70	M	Lt	MVA	3	1	5	MRF, HPT	17
2	52	M	Rt	Hit by mass	3	1	5	MRF, HPT	70
3	56	M	Lt	MVA	2	1	5	MRF, HPT	7
4	33	M	Lt	MVA	2	1	4	-	18
5	45	M	Lt	Sports injury	3	1	4	-	8
6	56	F	Lt	Simple fall	3	1	4	-	7
7	51	M	Rt	Hit by mass	2	1	4	MRF, HPT	9
8	19	M	Rt	MVA	2	1	3	MRF	12
9	43	M	Rt	Sports injury	3	1	3	-	7
10	64	M	Lt	Fall from height	3	1	3	MRF	8
11	49	M	Rt	Simple fall	3	1	3	-	19
12	74	M	Rt	Fall from height	2	1	4	-	6

M, male; Lt, left; MVA, motor vehicle accident; MRF, multiple rib fractures; HPT, hemopneumothorax; Rt, right; F, female.

Table 2. The results of coracoid process fixation with or without acromioclavicular joint stabilization

Patient no.	Union (mo)	Coracoid fixation	Acromioclavicular fixation	Time to removal (mo)	VAS score	UCLA score	UCLA grade	Complication
1	3	Cannulated screw	-	-	0	32	Good	
2	4	Cannulated screw	K-wire	2	0	32	Good	
3	4	HCS	K-wire	1.5	2	30	Good	
4	2	HCS	Hook plate	7.5	0	35	Excellent	
5	3	HCS	Hook plate	5	0	33	Good	
6	4	HCS	Hook plate	6.5	2	29	Good	
7	2	HCS	Hook plate	3	2	29	Good	
8	1.5	Cannulated screw	Hook plate	11	0	31	Good	
9	4	HCS	Hook plate	7	2	32	Good	
10	3	HCS	Hook plate	4.5	2	31	Good	
11	2.5	HCS	Hook plate	3	4	29	Good	
12	-	HCS	K-wire	1.5	4	28	Good	Nonunion at 6 mo

VAS, visual analogue scale; UCLA, University of California, Los Angeles; HCS, headless compression screw; K-wire, Kirschner wire.

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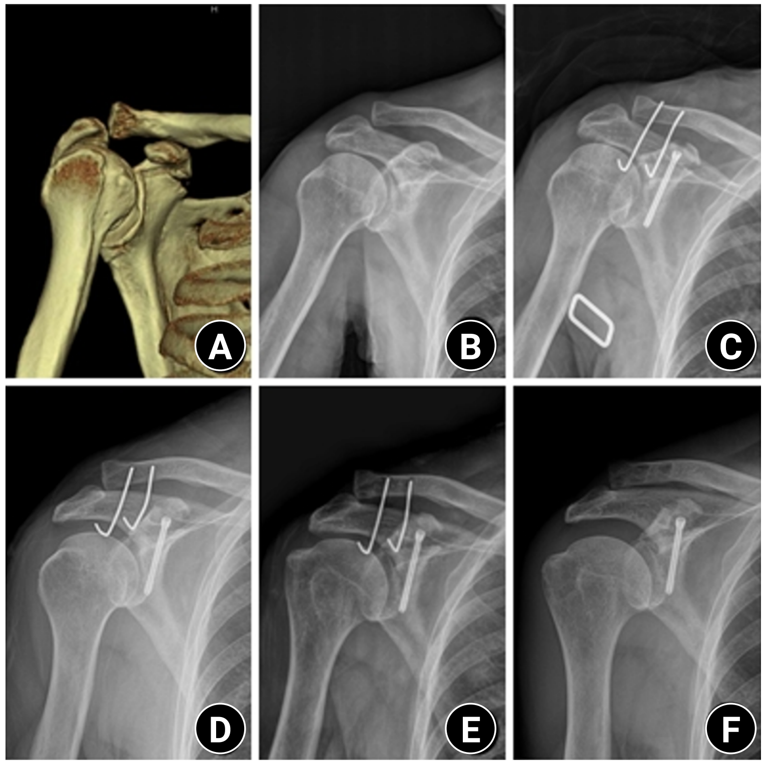

Fig. 2. Three-dimensional computed tomography (A) and shoulder anteroposterior (AP) radiograph (B) of a 74-year-old male patient show a coracoid process fracture associated with an acromioclavicular joint (ACJ) injury. (C) A 3.0-mm headless compression screw was used for the coracoid process fracture, and two Kirschner (K)-wires were used for the ACJ injury. (D) Postoperative 2-week radiographs show K-wire deformation. (E) Postoperative 6-week radiographs show K-wire loosening. (F) Postoperative 6-month AP radiographs show nonunion of the coracoid process.

Ogawa type I, with Eyres classifications ranging from types 3 to 5. Radiologic union occurred in 11 of 12 cases, with a mean time to union of 3 months. K-wires were removed earlier than hook plates. The final VAS score was 1.5, and the UCLA shoulder score was 30.9. One case of nonunion retained functional use.

Interpretation and comparison with previous studies

This study aimed to evaluate the usefulness of coracoid process fixation with or without ACJ stabilization procedure. Wignadasan et al. [6] reported that they achieved all bone union using a clavicle hook plate in six patients with concomitant coracoid base fracture and ACJ disruption, with a mean age of 39.8 years and a mean union time of 3.75 months. Ye et al. [7] showed that among 18 patients of coracoid process fractures combined with ACJ dislocation, bone union was achieved in 15 patients (83.3%) when only ACJ fixation using a clavicle hook plate was performed, and the mean age was 38 years. In our study, we demonstrated bone union in 11 out of 12 cases (91.7%) using coracoid process fixation with or without ACJ stabilization procedure for coracoid process fracture associated with the ACJ injury, with a mean age of 51 years and a mean union time of 3 months. Compared to the indirect reduction of the coracoid process fracture by performing ACJ fixation alone using a clavicle hook plate, the mean age was older and the bone union time and nonunion rate were lower in this study. We believe that coracoid process fixation with or without ACJ stabilization procedure may be considered a good alternative technique that appeared favorable than ACJ fixation alone.

In a comparative study of scaphoid screws, Shaw [14] reported that screws with larger head diameters and thread sizes showed greater compressive forces than headless screws. The mean maximum compressive forces were 12.8 kg for the 4.0 mm cancellous screw, 11.7 kg for the 3.5 mm cancellous screw, 7.6 kg for the 2.7 mm cortical screw, and 2.7 kg for the Herbert screw. In a comparative study of 6.5

mm Herbert screws and headed screws, Marshall et al. [15] showed that a cancellous lag screw with a washer was significantly better compressive force and pullout resistance than Herbert screw of same size. In this study, a 70-year-old patient (case 1) achieved bone union using only a cannulated screw with washer for coracoid fixation without acromioclavicular fixation. In cases of nonunion (case 12), a HCS was used for coracoid fixation. Coracoid fixation using a cannulated screw with a washer appears to be more beneficial than a headless screw in achieving sufficient fracture stability.

Ogawa et al. [3] reported that among 80 cases of coracoid base fracture with concurrent injuries, 62 cases underwent surgical treatment and achieved bone union in all cases, resulting in satisfactory results. Of these, 17 cases were coracoid base fracture associated with the ACJ injury, and the mean age was 36 years. Fixation with screw and washer for coracoid fractures and transacromial fixation with K-wire for the ACJ dislocation was performed. Rhee et al. [16] showed in a comparative study on ACJ stabilization using K-wires transfixation versus locking hook plates fixation in the treatment of acute ACJ dislocation that the locking hook plate provided more stable than the K-wires. In this study, deformation and loosening of K-wires occurred in patients with nonunion, and clavicle hook plates were thought to be more effective than K-wires in preventing nonunion.

In ACJ injury, Tossy classification grade III includes Rockwood classification type III and V, so this classification system applies to high-grade injuries [17]. In this study, Tossy classification grade 2 was observed in five of 12 cases. In coracoid process fractures associated with ACJ injuries, the Tossy classification, which is evaluated solely on plain radiography, is considered insufficient for assessing ACJ injuries. If a coracoid process fracture is confirmed, additional radiographic examinations, such as weighted, cross-arm AP, Zanca views, or magnetic resonance imaging (MRI), may be required.

Ye et al. [7] reported three cases of coracoid process nonunion that showed satisfactory functional outcomes despite nonunion. This study achieved satisfactory clinical results in all cases, including nonunion.

Limitations

The present study has certain limitations that should be acknowledged. Firstly, the small number of included patients underscores the necessity for future comparative studies with a larger sample size and extended follow-up periods. Secondly, coracoclavicular and acromioclavicular ligament damage could not be confirmed because there was no MRI scan that could detect surrounding soft tissue damage. Thirdly, the absence of biomechanical studies is also a challenge that needs to be addressed. Fourth, it is important to note that the present study is retrospective. However, the strength of this study is that the surgeries were performed at a single center using the same surgical technique and products from the same company, although there were some differences in fixation devices.

Clinical implication

We were able to achieve bony union in all but one case of coracoid process fracture associated with ACJ injury by fixation of the coracoid process with or without ACJ stabilization procedure. The use of a cannulated screw with washer for coracoid fixation appears to be more beneficial than a headless screw in achieving sufficient fracture stability. For ACJ stabilization procedures, clavicle hook plates have been considered more effective than K-wires in preventing nonunion. Tossy classification is based solely on plain radiography, which are considered insufficient to evaluate ACJ injuries, and further examination is considered necessary to definitively confirm the presence of an injury. Fortunately, satisfactory clinical results were achieved in all cases, including nonunion.

Generalizability

As a small, retrospective single-center case series, findings generalize mainly to surgically treated coracoid fractures with ACJ injury in similar trauma settings using CT-based evaluation and comparable implants/rehabilitation.

Conclusions

Coracoid process fixation with or without ACJ stabilization for coracoid process fractures associated with ACJ injury is an effective method that provides clinically beneficial fixation. If possible, a cannulated screw with a washer that has strong coracoid compression and pullout resistance and sufficient fracture stability is considered to be a good choice when performing both ACJ stabilization and coracoid fixation. If possible, a clavicle hook plate that provides

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sufficient fracture stability as an ACJ stabilization is considered to be a good choice when performing both ACJ and coracoid process fixation.

Article Information

Author contributions

Conceptualization: DS. Data curation: DS, SC. Formal analysis: BHK. Investigation: DS, SC, SK. Supervision: DS, BHK. Visualization: SC, BHK. Writing-original draft: DS, BHK. Writing-review & editing: DS, SC, SK, BHK. 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

Contact the corresponding author for data availability.

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Supplementary materials

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Rim plate-assisted intramedullary nail and plate combination technique for complex tibial plateau-to-diaphysis fractures: a technical note and case series

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Complex tibial plateau-to-diaphysis fractures present a significant surgical challenge due to their intricate fracture patterns and frequent association with severe soft tissue damage and concomitant injuries. This technical note introduces a novel fixation strategy: the rim plate-assisted intramedullary nail-plate combination (NPC) technique. In this approach, a rim plate simplifies the conventional NPC procedure by unifying the tibial plateau fracture into a single structural segment. This modification eliminates the need to address the articular and diaphyseal components simultaneously while enhancing articular stability. Furthermore, the technique preserves soft tissue integrity and promotes early rehabilitation. Clinical case examples demonstrate its successful application in managing complex tibial plateau-to-diaphysis injuries.
Level of evidence: V.

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Technical Note

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Introduction

Complex tibial plateau-to-diaphysis fractures are challenging to treat owing to their complexity and association with high-energy trauma, which often results in soft tissue damage and concomitant injuries [1-3]. Fixation with dual plating using a minimally invasive plate osteosynthesis (MIPO) technique can be a relatively less demanding technical challenge. However, the common drawback of this technique is the inability to allow early weight bearing compared with intramedullary (IM) nailing, particularly in patients with bilateral lower limb fractures [3,4]. Moreover, these injuries are often open fractures, which typically involve the anteromedial aspect of the tibia and can complicate dual plate fixation [2-4]. Conversely, IM nailing allows early rehabilitation of patients with diaphyseal fractures and is less affected by the soft tissue status. However, IM nailing alone may displace the plateau fracture during the procedure and may not achieve sufficient fixation of the articular component [4]. Addition of rafting screws with IM nailing can be a useful treatment option to enhance articular support [5]. However, rafting screws alone are less effective in preventing articular subsidence or angular deformity than fixed-angle constructs, particularly when the fracture involves a complex tibial plateau component [6].

To overcome the limitations of each fixation method, the IM nail-plate combination (NPC) technique was introduced as a potentially valuable alternative for addressing complex tibial plateau-to-diaphysis fractures [3,4]. However, the NPC technique for plateau-to-diaphysis fractures can be technically demanding, as it requires simultaneous management of both fracture components. In this regard, the rim plate-assisted NPC technique introduced in this study simplifies the conventional NPC procedure while further promoting stable articular fixation. This technique was applied in two patients with complex tibial plateau-to-diaphysis fractures accompanied by soft tissue injury and concomitant contralateral lower limb fractures, where a stable fixation construct was essential to enable early rehabilitation.

Case report

Ethics statement

This study was conducted in accordance with the tenets of the Declaration of Helsinki and its later amendments with approval from the Institutional Review Board (IRB) of Yeungnam University Medical Center (IRB No. YUMC 2025-09-021). Informed consent for participation was obtained from all participants in accordance with institutional and ethical guidelines. The patients also provided written informed consent for the publication of this report and the accompanying images.

Case 1

A 54-year-old male patient presented after a motor vehicle accident with multiple open wounds and a complex right-sided tibial plateau-to-diaphysis fracture (Fig. 1). On the contralateral side, he sustained multiple fractures involving the femoral neck and shaft. On the day of injury, initial management included open wound debridement and negative-pressure wound therapy, followed by external

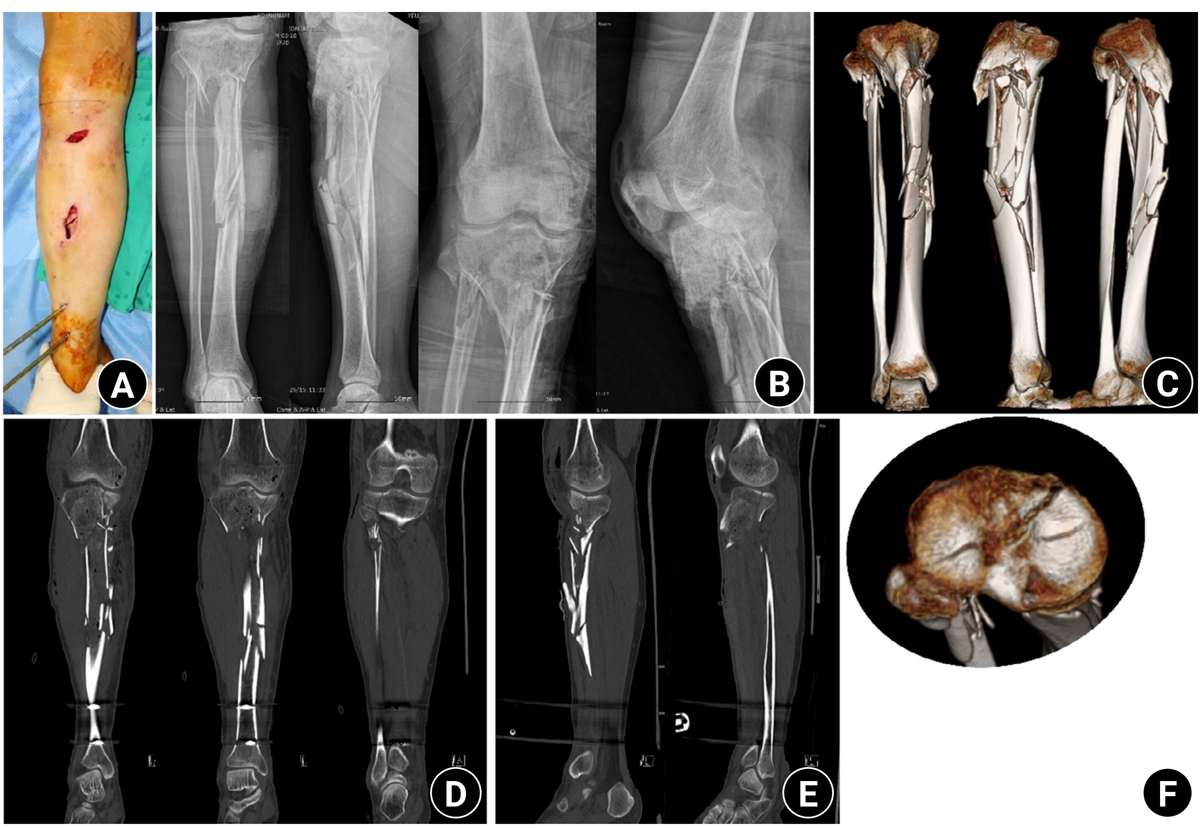

Fig. 1. Preoperative photographs and imaging studies. (A) Clinical photograph showing multiple open wounds on the anteromedial aspect of the lower leg. (B) Plain radiograph of a complex tibial plateau-to-diaphysis fracture. (C) Three-dimensional computed tomography (3D-CT) image revealing a comminuted plateau-to-diaphysis tibial fracture. (D) Coronal CT image demonstrating a bicondylar tibial plateau fracture. (E) Sagittal CT image showing posterolateral and anteromedial tibial plateau fractures. (F) 3D-CT image illustrating the overall fracture morphology of the tibial plateau.

fixation of the right tibial plateau and diaphyseal fractures. Definitive surgery for the right tibial plateau-to-diaphysis fractures was performed 8 days after injury, during which a rim plate-assisted NPC technique was planned. This approach was employed because the patient had multiple open wounds on the anteromedial aspect, and dual plating could have exposed the medial plate or require flap coverage. Furthermore, the presence of multiple contralateral limb injuries inhibited partial weight bearing. Once weight bearing began, the injured tibia would bear the full weight from the start. Therefore, the fixation construct must be strong enough to allow immediate full weight bearing to enable early rehabilitation.

Surgical technique

The procedure started by placing a rim plate to convert the tibial plateau fracture into a single articular segment. The surgical approach was chosen based on the fracture pattern. The patient had posterolateral and anteromedial tibial plateau fractures. To address the posterolateral fracture, a modified anterolateral approach was employed, extending through the space between the fibular collateral ligament (FCL) and the posterolateral plateau rim [7,8]. The anteromedial fracture was approached through an anteromedial incision of approximately 5 cm, extending from the proximal medial open wound. Long incisions were not required, as the exposure was sufficient for fracture reduction and rim plate placement. The medial collateral ligament was incised longitudinally at the fracture site to confirm intraarticular reduction. The posterolateral plateau fracture was reduced using a colinear clamp. A 2.7-mm variable-angle locking compression plate (VA-LCP; Variable Angle LCP Forefoot/Midfoot System 2.4/2.7, Synthes GmbH) was contoured and inserted into the posterolateral space beneath the FCL. The contoured plate and posterolateral fragment were pressed together with a pointed reduction bone clamp (Fig. 2A and 2B). To maintain compression, a 2.7-mm cortical screw was inserted into the most anterior hole, followed by 2.7-mm locking screws to secure the plate and connect the posterolateral fragment with the anterolateral main fragment at the plateau rim. On the anteromedial side, another 2.7-mm VA-LCP was con-

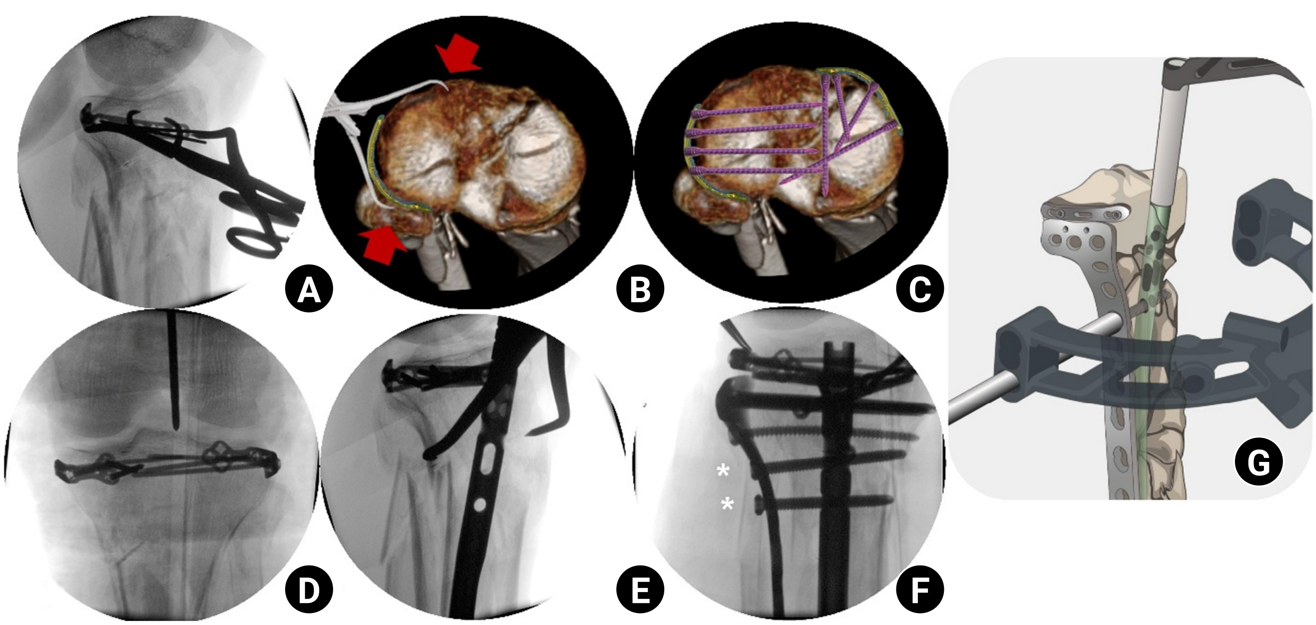

Fig. 2. Fluoroscopic images and schematic illustrations of the rim plate-assisted intramedullary nail-plate combination technique. (A, B) A contoured 2.7-mm variable-angle locking compression plate (VA-LCP) was applied to the posterolateral plateau via a modified anterolateral approach, followed by anterior-to-posterior compression (red arrows). (C, D) A second 2.7-mm VA-LCP was fixed to the anteromedial plateau, unifying the articular fragments into a single segment. (E) A bone clamp was used to maintain reduction during reaming and nail insertion. (F, G) A 4.5-mm proximal tibia plate was applied, with 5.0-mm interlocking screws (asterisks) linking the plate to the intramedullary nail using the aiming arm guide.

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toured and positioned over the medial collateral ligament. A pointed bone reduction clamp was used to achieve medial-to-lateral compression, and 2.7-mm locking screws were inserted. This construct restored the tibial plateau as a single segment (Fig. 2C and 2D). In these procedures, care was taken to avoid directing screws toward the anterior center, which could obstruct IM nail passage. However, most screws—being oriented nearly perpendicular to the cortical surface and positioned within the allowable variable screw angulation of up to 30°—generally do not interfere with the trajectory of the IM nail. Therefore, it was sufficient to ensure that screws inserted through the anterior holes of the plate did not point excessively anteriorly. Once the plateau was stabilized as a single segment, IM nailing was performed through the suprapatellar approach to minimize the displacement of the proximal fragment. To prevent the displacement of the plateau segment during nail entry, both the tibial tuberosity and posterolateral aspect were secured with a pointed bone reduction clamp (Fig. 2E). During nailing, overall lower limb alignment was confirmed using the alignment rod before screw fixation. Only three cancellous screws could be inserted into the proximal segment. Additional anterolateral tibial plating was performed to improve the stability of the construct. A 4.5-mm LCP Proximal Tibia Plate (Synthes GmbH) was positioned using a MIPO technique. Fine adjustment of the plate position enabled linkage with the IM nail, a process that was technically straightforward. A drill sleeve was inserted through the proximal aiming arm of the IM nail (Expert Tibia Nail, Synthes GmbH), and the plate was adjusted to precisely align with the drill sleeve. Subsequently, 5.0-mm interlocking screws were inserted through the plate holes, connecting the transverse locking hole and the oblong slot of the IM nail to link the nail and plate (Fig. 2F and 2G). More 5.0-mm locking screws were added to the proximal holes of the plate to secure it to the proximal tibial section. For distal fixation, one 4.5-mm cortical screw and several 3.5-mm locking screws were inserted using a 3.5-mm locking attachment plate (Synthes GmbH). This was performed to avoid interference with the IM nail, completing the final fixation. Finally, the open wounds on the anteromedial aspect of the tibia were closed directly because no medial plate was applied. Postoperative plain radiographs and computed tomography (CT) images are shown in Fig. 3.

Postoperative course after the rim plate-assisted NPC technique

Knee joint range-of-motion exercises were initiated immediately after surgery. Two weeks after surgery, the right tibial anteromedial open wounds had healed without complication. Assisted ambulation began 4 weeks after surgery, and by 6 weeks, the patient could ambulate independently with a walker, and fracture reduction was sustained in both lower limbs (Fig. 4A and 4B). Complete bone union was achieved for all fractures 6 months after surgery. The early initiation of rehabilitation helped the patient regain the ability to perform daily living activities, and at the 1-year follow-up, full functional recovery was confirmed (Fig. 4C and 4D).

Case 2

A 23-year-old male patient presented with multiple traumatic injuries, including an aortic dissection, following a motorcycle accident. Initial assessment and resuscitation were performed according to the Advanced Trauma Life Support guidelines. Musculoskeletal injuries included a left complex tibial plateau-to-diaphysis fracture, along with other bilateral lower extremity fractures (Fig. 5). The complex left tibial plateau-to-diaphysis fracture was associated with compartment syndrome and severe skin contusion (Fig. 5A). On the day of injury, left lower leg fasciotomy was performed to address the compartment syndrome, and an external fixator was applied. One week later, the other open fractures were treated first, and another week later, definitive fixation of the left complex tibial plateau-to-diaphysis fracture was performed.

Surgical technique

As in case 1, the procedure started with converting the tibial plateau fracture into a single segment using a rim plate. An anterolateral approach was chosen because of the anterolateral location of the main fracture. The patient had a lateral condylar depression of the tibial plateau, which was initially elevated using an impactor (Fig. 6A). After the elevation of the depressed fragment, Kirschner wires were temporarily fixed through the inside-out technique [9]. A 2.7-mm VA-LCP was then shaped and positioned, followed by medial-to-lateral compression using a colinear clamp (Fig. 6B). Both cortical and locking screws were inserted through the VA-LCP, which connected the plateau

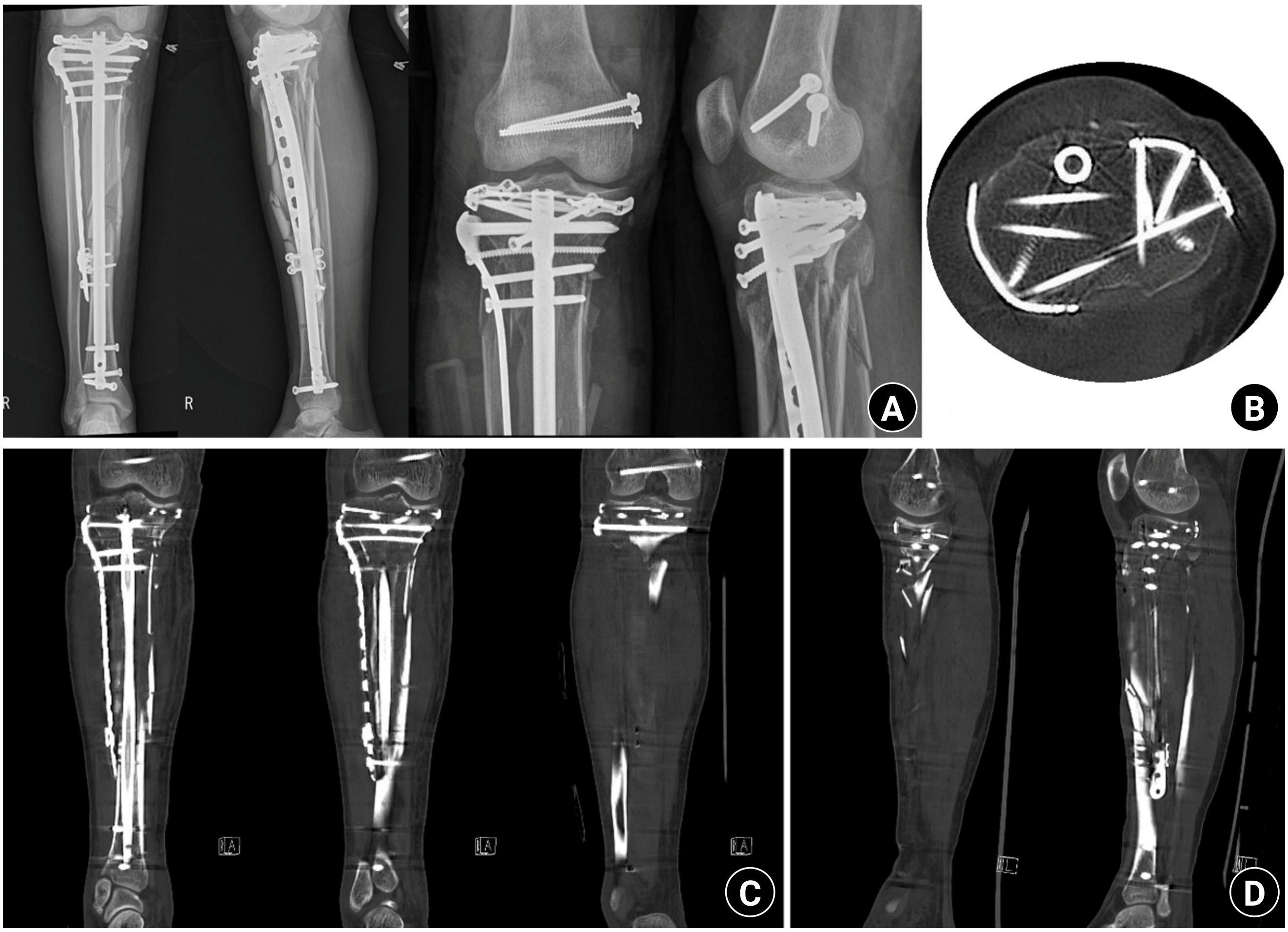

Fig. 3. Postoperative plain radiographs and computed tomography (CT) images. (A) Postoperative plain radiograph. (B) Axial CT image confirming that screws from the rim plate did not interfere with the intramedullary nail trajectory. (C) Coronal CT image after fixation. (D) Sagittal CT image after fixation.

fragments into a single segment (Fig. 6C). A suprapatellar approach was employed for IM nailing (Fig. 6D). As in case 1, only three cancellous screws could be inserted into the proximal fragment through the IM nail. To enable immediate full weight bearing, an additional plate was applied to augment fixation, which completed the NPC technique (Fig. 6F). In this patient, the longest available 4.5-mm LCP proximal tibia plate did not provide sufficient construct length. Therefore, a 4.5-mm LCP proximal lateral tibia plate was used instead; this plate has a proximally oblique design, in contrast to the sharply angled, inverted "L"-shaped design of the standard proximal tibia plate. Postoperative plain radiographs and CT images are shown in Fig. 7.

Postoperative course following the rim plate-assisted NPC technique

One week later, the left distal radius and ulna and concomitant ipsilateral forearm both-bone fractures were surgically treated, which concluded the surgical procedures. Passive knee range-of-motion exercises were initiated immediately after surgery. Weight bearing and walking ambulation began approximately 4 weeks after surgery, following transfer from the intensive care unit to the general ward. Six weeks after surgery, the patient could walk independently (Fig. 8A and 8B), and bone union was achieved at 6 months. At 9 months, the patient underwent reconstruction of the posterior cruciate ligament to address right knee instability and was subsequently able to return to full physical activity (Fig. 8C and 8D).

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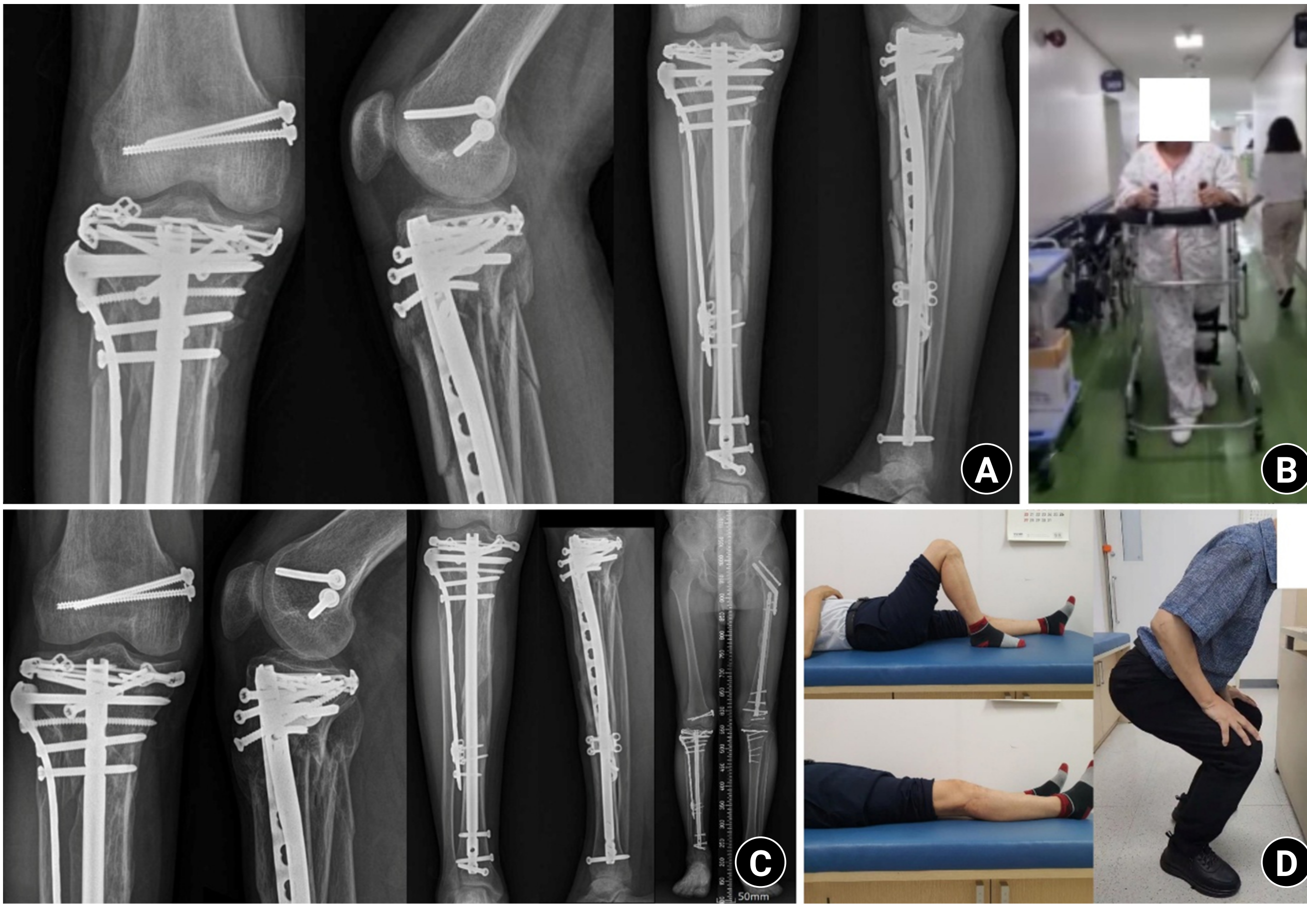

Fig. 4. Follow-up plain radiographs and clinical photographs taken 6 weeks and 1 year after surgery. (A) Plain radiographs 6 weeks postoperatively. (B) Clinical photograph showing the patient ambulating with a walker 6 weeks after surgery. (C) Plain radiographs taken 1 year postoperatively. (D) Clinical photographs 1 year after surgery showing good knee joint range-of-motion and the ability to perform squatting exercises.

Discussion

Complex tibial plateau-to-diaphyseal fractures are rare and present significant treatment challenges, with limited literature on effective management strategies. This technical note and accompanying case report present the successful outcomes of the rim plate-assisted NPC technique tailored for these challenging injuries. A key challenge in managing such fractures lies in achieving and maintaining simultaneous reduction of both the plateau and diaphyseal components before fixation, which can be technically demanding. The rim plate helps in overcoming this issue by enabling secure reduction and stabilization of the plateau fracture initially, effectively converting the injury into an extra-articular configuration. This approach simplifies the subsequent IM nailing through the creation of a unified proximal segment, thereby facilitating easier and more reliable assembly of the NPC construct. Additionally, the application of a 4.5-mm plate through the MIPO technique enhances construct stability through the fixed-angle support to the proximal fragment. As the cases demonstrated, this method allowed for early rehabilitation, even in patients with concomitant contralateral lower limb fractures that prohibited partial weight bearing. Moreover, the technique helps maintain the integrity of soft tissue, particularly in the anteromedial region, which is often compromised in high-energy injuries, offering a practical advantage over conventional dual plating methods.

Kubiak et al. [2] introduced the NPC technique for the treatment of ipsilateral, noncontiguous unicondylar tibial plateau and diaphyseal fractures. Compared with the cases presented in the current study, their cases involved

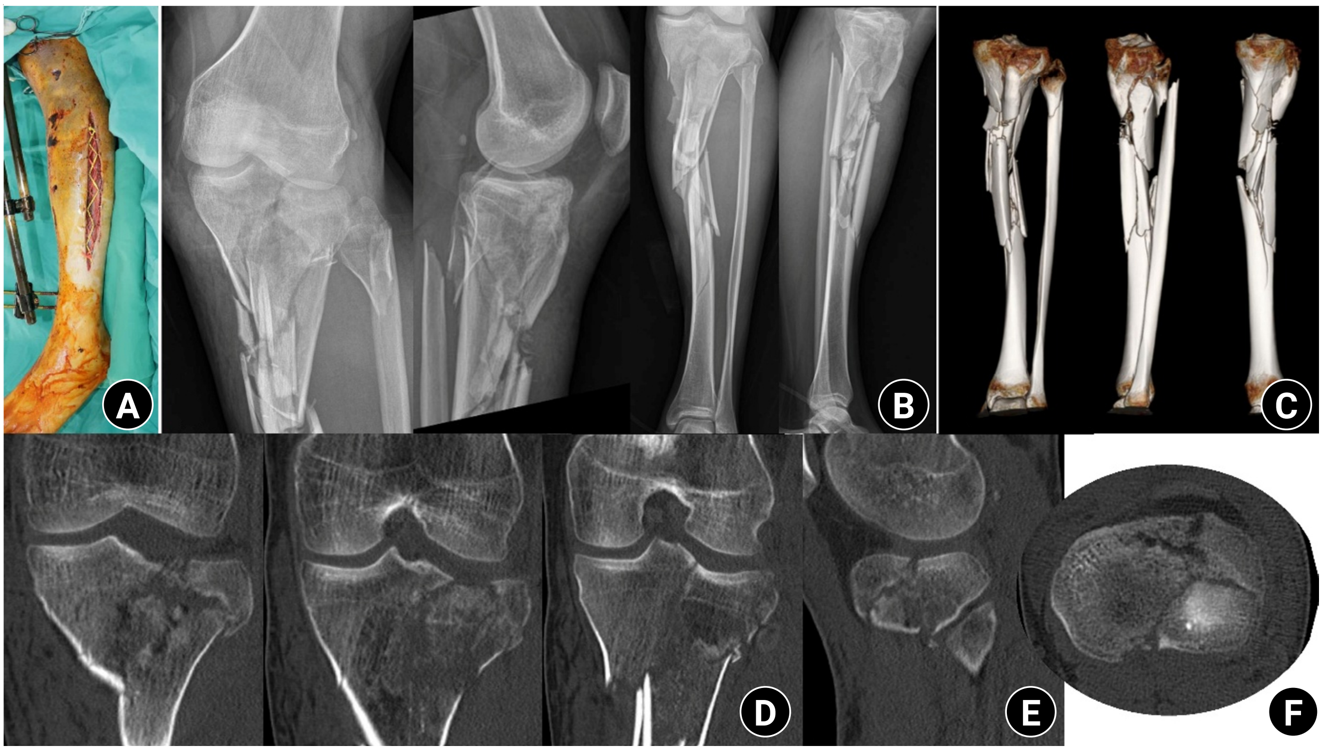

Fig. 5. Preoperative photographs, plain radiographs, and computed tomography (CT) images. (A) Clinical photograph showing compartment syndrome of the lower leg with multiple necrotic skin contusions. (B) Preoperative plain radiograph. (C) Preoperative three-dimensional CT image. Preoperative coronal (D), sagittal (E), and axial. (F) CT images demonstrating depression and splitting of the lateral tibial plateau.

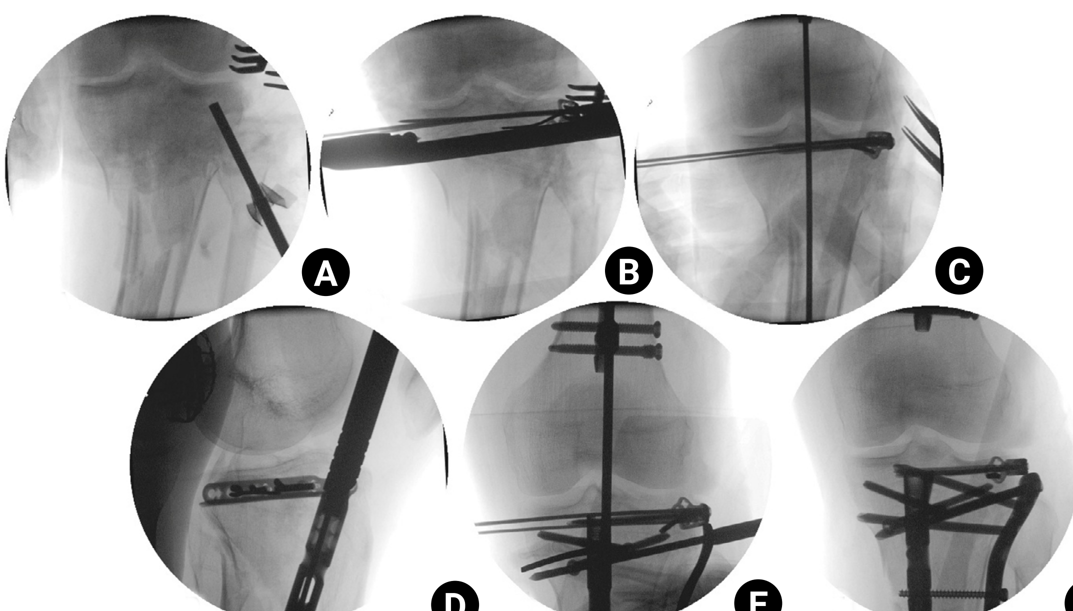

Fig. 6. Fluoroscopic images and schematic illustrations of the rim plate-assisted intramedullary nail and plate combination technique. (A) Lateral plateau depression was elevated. (B, C) A contoured 2.7-mm variable-angle locking compression plate was applied with medial-to-lateral compression and fixed to unify the plateau into a single segment. (D) Intramedullary nailing was performed via the suprapatellar approach. (E) Alignment was confirmed with a rod. (F) A 4.5-mm proximal lateral tibia plate was added for final fixation.

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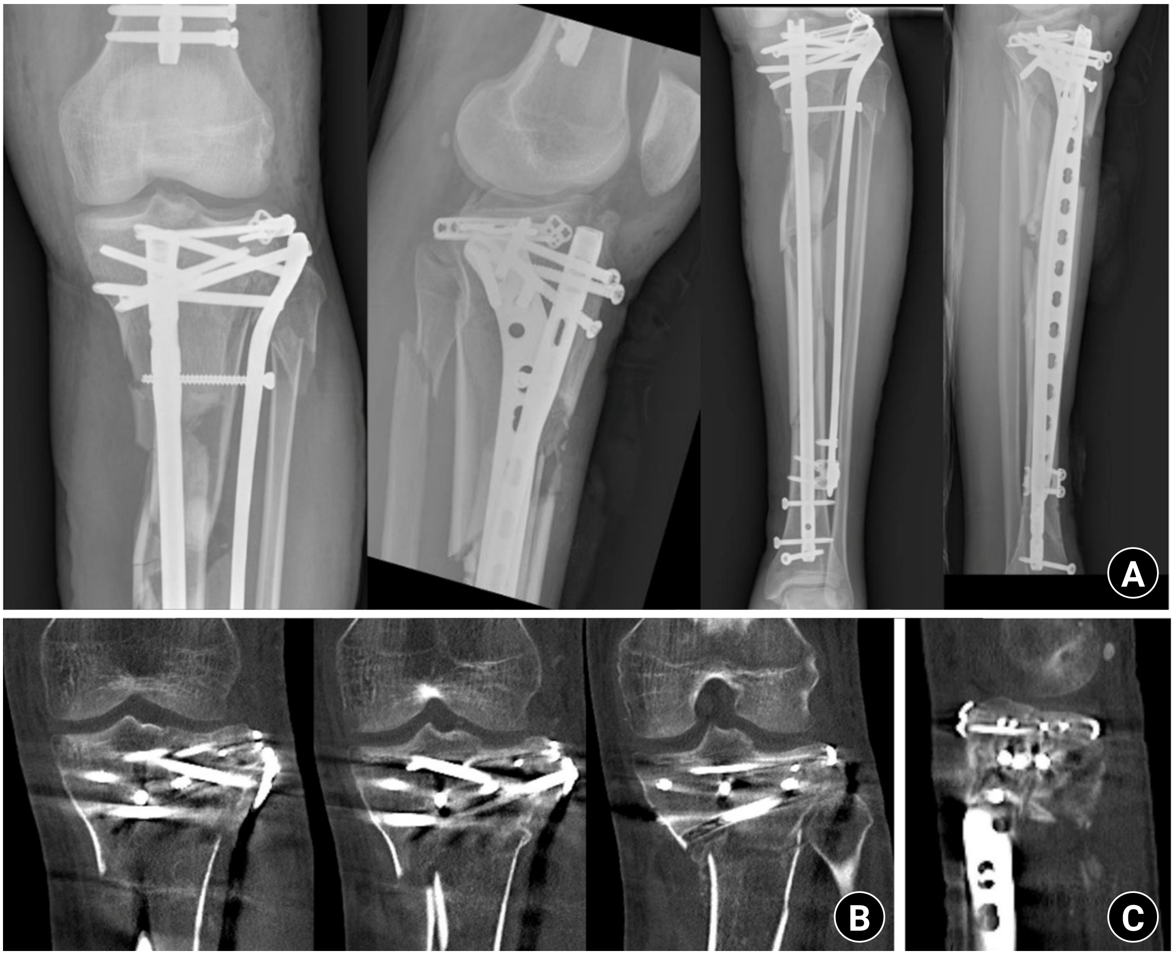

Fig. 7. Postoperative plain radiograph and computed tomography (CT) images. (A) Postoperative plain radiograph. (B) Coronal and (C) sagittal CT images after fixation.

noncontiguous fractures, which allowed for sequential reduction and fixation: the articular portion of the plateau was first reduced and stabilized using a proximal tibial plate without a rim plate, followed by IM nailing for the diaphyseal component. They also emphasized that IM nailing is a more attractive option for managing the soft tissue around tibial diaphyseal fractures. Their approach yielded successful outcomes. In noncontiguous fractures, as described by Kubiak et al. [2], the NPC technique alone may be sufficient, as the plateau fracture can be addressed independently with a proximal tibial plate, while the diaphyseal fracture can be treated separately with IM nailing. However, in cases of ipsilateral contiguous tibial plateau and diaphyseal fractures, such as those presented in the current study, simultaneous reduction and fixation of both the articular and diaphyseal components should be achieved through the proximal tibial plate. This renders the procedure technically more demanding than in noncontiguous cases. To simplify this process, the rim plate serves to convert the fractured plateau into a single stable segment, thereby facilitating subsequent reduction and fixation using the NPC technique in cases of contiguous tibial plateau and diaphyseal fractures.

Wright et al. [3] and Marks et al. [4] also reported favorable outcomes using the conventional NPC technique in bicondylar and complex plateau-to-diaphysis fractures, respectively. Their results highlighted the advantages of the NPC construct, including preservation of medial soft tissue, shorter time to definitive fixation, and the possibility of early rehabilitation. Our rim plate-assisted NPC technique builds upon these principles but, as described above, differs from the conventional NPC in that it avoids

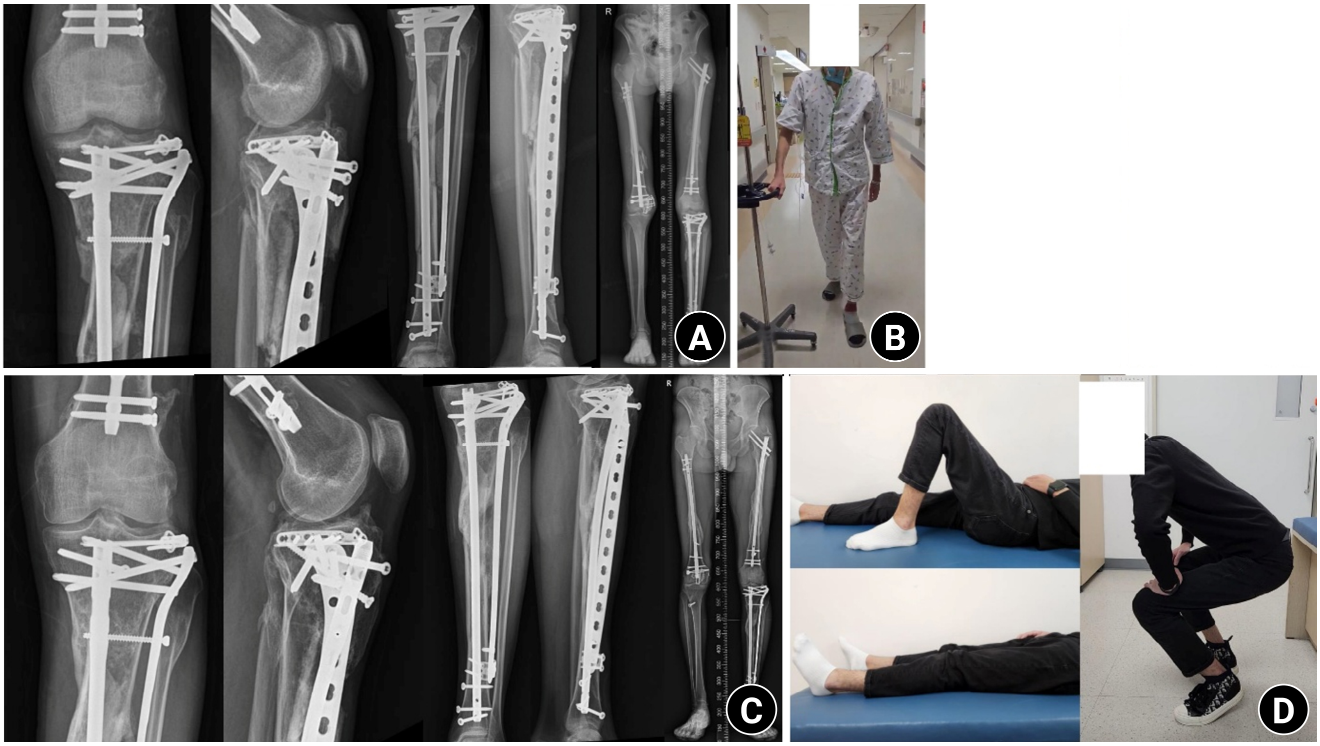

Fig. 8. Follow-up plain radiographs and clinical photographs taken 6 weeks and 1 year 6 months after surgery. (A) Plain radiographs 6 weeks postoperatively. (B) Clinical photograph showing the patient walking independently 6 weeks after surgery. (C) Plain radiographs 1 year 6 months postoperatively. (D) Clinical photographs 1 year 6 months after surgery showing good knee range-of-motion and the ability to perform squatting exercises.

simultaneous management of both fracture components by enabling a stepwise, sequential approach.

Rojas et al. [1] introduced the "umbrella technique," which involves the use of a circumferentially precontoured minifragment long plate positioned beneath the patellar tendon through both anteromedial and anterolateral incisions to stabilize the tibial plateau prior to IM nailing, as demonstrated in three cases of complex tibial plateau-to-diaphysis fractures. This technique is designed to provide stability against hoop stress, and—similar to our approach—it emphasizes favorable outcomes in soft tissue–compromised cases compared with traditional plating. However, our method differs in that it uses rim plates in a fracture-specific manner to further minimize soft tissue disruption, while incorporating a 4.5-mm plate to complete the NPC construct. Although our technique does not achieve hoop stress resistance through full anterior circumferential coverage of the tibial plateau, the screws from the rim plate—applied following medial-to-lateral compression—and those from the 4.5 mm plate are believed to provide sufficient stability. Notably, in the second case reported by Rojas et al. [1], follow-up radiographs revealed posterior tilting of the proximal segment. This may have occurred because, although the circumferential plate provides hoop stress resistance, it does not offer fixed-angle stability to the proximal segment, and the proximal cancellous screws of the nail alone likely failed to sufficiently compensate for this mechanical deficiency.

This study has several limitations. The findings based on only two case reports cannot be generalized; thus, further analysis involving a larger number of cases using this technique is warranted. Nevertheless, this report presents a useful surgical strategy for managing challenging complex tibial plateau-to-diaphyseal fractures, which may offer practical guidance to surgeons treating similar cases. In relatively simple fractures, the additional use of a rim plate may offer limited benefit relative to the increased surgical time and effort. Thus, the advantages of this technique should be weighed carefully against its invasiveness and operative complexity. Lastly, in case 1, two

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5.0-mm interlocking screws of the IM nail were inserted through the proximal tibial plate to link the two implants. additionally, in comminuted fracture zones where screw purchase through the proximal tibial plate was not feasible, the screws achieved purchase in the IM nail. However, a limitation of this procedure is that there is currently no biomechanical evidence supporting this linking technique; therefore, further biomechanical studies are warranted.

The rim plate-assisted NPC technique may be a practical solution for achieving early rehabilitation and avoiding soft tissue complications in patients with complex tibial plateau-to-diaphyseal fractures, particularly those with bilateral lower limb injuries and multiple open wounds. The rim plate helps simplify the NPC procedure and provides supplemental fixation for the articular component of the plateau fracture. This technique may aid surgeons in managing these challenging injuries more effectively.

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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Instructions for authors

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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.

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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.
- Role of corresponding author: The corresponding author takes primary responsibility for communication with the journal during the manuscript submission, peer review, and publication process. The corresponding author typically ensures that all of the journal's administrative requirements, such as providing the details of authorship, ethics committee approval, clinical trial registration documentation, and conflict of interest forms and statements, are properly completed, although these duties may be delegated to one or more co-authors. The corresponding author should be available throughout the submission and peer-review process to respond to editorial queries in a timely manner, and after publication, should be available to respond to critiques of the work and cooperate with any requests from the journal for data, additional information, or questions about the article.
- 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.

- AI cannot be listed as an author: AI tools cannot be listed or cited as authors due to their inability to take responsibility for errors.
- Reliability, responsibility, and permissible use of AI: Authors are fully responsible for the reliability, accuracy, originality, and integrity of their manuscripts when using AI tools. They must take complete responsibility for any plagiarism or false information generated by AI. AI-generated content cannot be cited as a primary source. The use of AI tools is permissible only for language editing or formatting assistance, and such use must be transparently disclosed.
- Data privacy and confidentiality: Authors must ensure that no confidential, sensitive, or personally identifiable data are entered into AI tools.
- Disclosure of AI use: Authors must disclose the use of AI tools at the time of manuscript submission. This disclosure should include the specific tools used, their model names, versions, manufacturers, and the role of the AI in the process. This information should be included in the Methods or Acknowledgments section, with detailed prompts included where relevant.
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- Restrictions for peer reviewers: Peer reviewers are prohibited from uploading manuscripts to external AI tools during the review process. If AI tools are used to support any part of the review, reviewers must transparently disclose this in their peer review reports.
- 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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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 be also 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.
- Editorials: Editorials are invited by the editors and should be commentaries on articles recently published in the journal. Editorial topics could include active areas of research, fresh insights, and debates in the field of orthopedic surgery. Editorials should not exceed 1,000 words, excluding references, tables, and figures. A maximum of 10 references and total 4 figures or tables are allowed.
- 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.

- Article Information: This section should include details on Author Contributions, Conflicts of Interest, Funding, Data Availability, Acknowledgments, and Supplementary Materials. If any of these items are not applicable, authors must indicate "None."
- The contributions of all authors must be described using the CRediT (https://credit.niso.org/) taxonomy of author roles.
- References must be numbered with superscripts according to their quotation order. 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 in a bracket ([ ]).
- 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."
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- The journals should be abbreviated according to the style used in the list of journals indexed in the NLM Journal Catalog (http://www.ncbi.nlm.nih.gov/nlmcatalog/journals).
- 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.
3. Raats JH, Ponds NH, Brameier DT, et al. Agreement between patient- and proxy-reported outcome measures in adult musculoskeletal trauma and injury: a scoping review. Qual Life Res 2024 Aug 23 [Epub]. https://10.1007/s11136-024-03766-1

② Book & Book chapter

4. Townsend CM, Beauchamp RD, Evers BM, Mattox K. Sabiston textbook of surgery. 21st ed. Elsevier; 2021.
5. Meltzer PS, Kallioniemi A, Trent JM. Chromosome alterations in human solid tumors. In: Vogelstein B, Kinzler KW, eds. The genetic basis of human cancer. McGraw-Hill; 2002. p. 93-113.

③ Homepage/Web site

6. World Health Organization (WHO). World health statistics 2021: a visual summary [Internet]. WHO; 2021 [cited 2023 Feb 1]. Available from: https://www.who.int/data/stories/world-health-statistics-2021-a-visual-summary

④ Preprint

7. Sharma N, Sharma P, Basu S, et al. The seroprevalence

and trends of SARS-CoV-2 in Delhi, India: a repeated population-based seroepidemiological study [Preprint]. Posted 2020 Dec 14. medRxiv 2020.12.13.20248123. https://doi.org/10.1101/2020.12.13.20248123

For more on references, refer to the NLM's "Samples of Formatted References for Authors of Journal Articles." https://www.nlm.nih.gov/bsd/uniform_requirements.html#journals

Figures and Figure Legends

Figures should be cited in the text and numbered using Arabic numerals in the order of their citation (e.g., Fig. 1). Figures are not embedded within the text. Each figure should be submitted as an individual file. The figure legends should begin on the next page after the last table. Every figure has its own legend. Abbreviations and additional information for any clarification should be described within each figure legend. Footnotes below the figure should follow the order of abbreviation first, followed by symbols. Symbols should be marked with small alphabet letters in the order of their usage, such as [a)], [b)], [c)], or asterisks (*) for statistical significance. Figure files are submitted in EPS, TIFF, or PDF formats. The requirement for minimum resolutions is dependent on figure types. For line drawings, 1,200 dpi are required. For grey color works (i.e., pictures of gel or blots), 600 dpi is required. For color or half-tone artwork, 300 dpi is required. The files should be named according to the figure number.

- Staining techniques used should be described. Photomicrographs with no inset scale should have the magnification of the print in the legend.
- Papers containing unclear photographic prints may be rejected.
- Remove any writing that could identify a patient.
- If any tables or figures are taken or modified from other papers, authors should obtain permission through the Copyright Clearance Center (https://www.copyright.com/) or from the individual publisher, unless they are from open-access journals under the Creative Commons License. For tables or figures from an open-access journal, simply verify the source of the journal precisely in the accompanying footnote. Please note the distinction between a free access journal and an open-access journal: it is necessary to obtain permission from the publisher of a free-access journal for using tables or figures published therein. Examples are shown below:
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- Additional information for any clarification should be designated for citation using alphabetical superscripts [a)], [b)], [c)] or asterisks (*) for statistical significance. The explanation for superscript citation should follow these examples: [a)]Not tested.
  *P< 0.05, **P< 0.01, ***P< 0.001.
- Tables should be understandable and self-explanatory, without references to the text.
- If a table has been previously published, it should be accompanied by the written consent of the copyright holder, and the footnote must acknowledge the original source.

7. MANUSCRIPT PROCESSING AFTER ACCEPTANCE

Final Version

After the paper has been accepted for publication, the authors should submit the final version of the manuscript. The names and affiliations of the authors should be double-checked, and if the originally submitted image files were of poor resolution, higher-resolution image files should be submitted at this time. Symbols (e.g., circles, triangles, squares), letters (e.g., words, abbreviations), and numbers should be large enough to be legible on reduction to the journal's column widths. All symbols must be defined in the figure caption. If references, tables, or figures are moved, added, or deleted during the revision process, renumber them to reflect such changes so that all tables, references, and figures are cited in numeric order.

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Before publication, the manuscript editor will correct the manuscript such that it meets the standard publication format. The authors must respond within two days when the manuscript editor contacts the corresponding author for revisions. If the response is delayed, the manuscript's publication may be postponed to the next issue.

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The authors will receive the final version of the manuscript as a PDF file. Upon receipt, the authors must notify the editorial office (or printing office) of any errors found in the file within two days. Any errors found after this time are the responsibility of the authors and will have to be corrected as an erratum.

Errata and Corrigenda

To correct errors in published articles, the corresponding author should contact the journal's Editorial Office with a detailed description of the proposed correction. Corrections that profoundly affect the interpretation or conclusions of the article will be reviewed by the editors. Corrections will be published as corrigenda (corrections of the author's errors) or errata (corrections of the publisher's errors) in a later issue of the journal.

NOTICE: These recently revised instructions for authors will be applied beginning with the January 2026 issue.

Checklist

- ☐ Manuscript in MS-WORD (DOC, DOCX) format.
- ☐ Double-spaced typing with 12-point font.
- ☐ Sequence of title page, abstract and keywords, introduction, methods, results, discussion, and conclusions, acknowledgments, references, tables, and figure legends. All pages and manuscript text with line should be numbered sequentially, starting from the abstract.
- ☐ Title page with article title, authors' full name(s) and affiliation(s), address for correspondence (including telephone number, and email address), running title (less than 50 characters), and acknowledgments, if any.
- ☐ Abstract in structured format up to 300 words for original articles. Keywords (up to 5) from the MeSH.
- ☐ All table and figure numbers are found in the text.
- ☐ Figures as separate files, in TIFF, JPG, GIF, or PPT format.
- ☐ References listed in proper format. All references listed in the reference section are cited in the text and vice versa.

JMT Journal of Musculoskeletal Trauma

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The corresponding author signs this copyright agreement on behalf of all the co-authors.

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Signature
By signing this conflict of interest form, each and every undersigned author agrees to the following: To the best of my knowledge, I have no relevant financial relationships except as follows (please list any possible exceptions below the author name).

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