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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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Current concepts in the management of phalangeal fractures in the hand

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This review focuses on the treatment of hand fractures based on the anatomical location of the fractured phalanx, excluding the thumb, and examines recent studies on the topic. The main points are as follows: in most cases of hand fractures, conservative treatment should be prioritized over surgical intervention. The three key factors in determining whether surgical treatment is necessary are (1) whether the fracture is intraarticular, (2) the stability of the fracture itself, and (3) the extent of damage to surrounding soft tissues. The primary surgical treatment is closed reduction and Kirschner-wire fixation. The risk of rotational deformity increases with fractures closer to the proximal region. Intra-articular fractures may lead to subsequent stiffness and arthritis; thus, computed tomography is recommended to assess the fracture pattern. Anatomic reduction of intraarticular fragments is required, along with correction of the inherent joint instability. No surgical method has proven to be superior; it is advantageous for the surgeon to choose a surgical approach they are familiar with and confident in, based on the specific fracture and patient factors. Complications in hand fractures are various; the most frequent is stiffness, and nonunion is uncommon. Early joint motion is crucial in minimizing the risk of stiffness.

Keywords: Bone fractures; Hand; Finger phalanges; Treatment

Review Article

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Introduction

Hand fractures are common, with an incidence of 3.7 cases per 1,000 males and 1.3 cases per 1,000 females, accounting for 10%–30% of all fractures [1,2]. Compared to the metacarpals, the fingers are more exposed to external forces, making them more susceptible to injury. Consequently, they constitute over 50% of hand fractures, with distal phalanx fractures, including tuft fractures, being the most prevalent [3].

Hand fractures occur due to various causes. Sports-related injuries are more common in younger individuals, whereas work-related injuries tend to increase with age and are more frequently observed in adult males. Among the elderly, falls and traffic accidents are the most common causes of injury and occur more often in females [4,5]. However, there is ongoing debate regarding which digit is most susceptible to fracture. Some studies suggest that the fifth digit may be more vulnerable because of its anatomical structure and position, while other research indicates that the index or middle fingers may be more prone to fracture depending on the mechanism of injury and exposure factors [5-7]. Approximately 70% of finger fractures are reported to occur in individuals between the ages of 11 and 45 [6].

Finger fractures are classified based on several factors, including the specific digit involved, the anatomical location of the fracture (proximal phalanx, middle phalanx, or distal phalanx), the fracture pattern (oblique, transverse, spiral, impacted, comminuted), the degree of displacement, the presence of joint involvement (fractures or dislocations), and the extent of soft tissue damage, including open fractures.

Despite the diverse and frequent patterns of finger fractures, they are often overlooked due to the small size of the bone fragments and their generally favorable healing process. However, finger fractures frequently involve complex injuries, including damage to tendons, nerves, and blood vessels, which may result in complications such as joint stiffness, weakness, malunion, traumatic arthritis, and functional sequelae of the hand. Therefore, accurate diagnosis and appropriate treatment are essential.

The goals of finger fracture treatment include achieving proper alignment, maintaining pain-free joints free from arthrosis, and ensuring a stable digit with a good range of motion (ROM) for functional movement [8]. Nevertheless, the majority of finger fractures do not require surgical intervention [5,9,10]. The three critical factors in determining the need for surgical treatment are the presence of an intraarticular fracture, the stability of the fracture, and the extent of soft tissue damage [11,12]. Stable extraarticular fractures can typically be managed conservatively. However, because of the wide variation in the location and pattern of finger fractures, establishing universal indications for surgical treatment is challenging [7]. Ultimately, the decision to perform surgical intervention rests with the treating surgeon. The choice of surgical technique also varies and includes options such as metal wires, screws, plates, and external fixation devices.

This review aims to evaluate recently published studies on the treatment of fractures according to the anatomical location of the finger bones, excluding thumb fractures.

Distal Phalangeal Fracture

Distal phalangeal fractures are the most common fractures of the hand, accounting for approximately 50% of all finger fractures, according to some studies [7,13]. The distal phalanx is anatomically divided into the tuft, shaft, and base. In the case of distal phalangeal fractures, the surrounding soft tissue damage and its management are often more critical than the fracture itself [14].

Tuft Fracture

The tuft fracture is the most prevalent type of distal phalanx fracture and occurs at the tip, distal to the tendon attachment site. It is primarily caused by crush injuries and often presents as a comminuted fracture. Tuft fractures are typically stable and can be treated conservatively due to the protection offered by the volar pulp and the fibrous soft tissue of the nail complex on the dorsal side. Stable pin fixation may be difficult to achieve due to the frequent comminuted nature of tuft fractures, and it may actually increase the risk of infection. Even when a fragment of the fractured tuft does not unite and remains a free bone fragment, it rarely results in symptoms. In symptomatic cases involving free bone fragments, removal of the fragment is performed, or, in very limited cases, osteosynthesis may be attempted [15]. A finger splint is applied to the distal interphalangeal (DIP) joint for 2 to 4 weeks to prevent stiffness, ensuring that the proximal interphalangeal (PIP) joint remains unaffected.

Tuft fractures are more likely to require attention to the damage to the perionychium surrounding the tuft rather than the fracture itself. Even in open fractures, the fracture can often be reduced simply by suturing the surrounding soft tissue [16]. In particular, when the nail (nail plate) is detached and the nail bed is torn or pulled away, the nail matrix should be examined and sutured to minimize deformation of the regenerating nail. In cases of subungual hematoma without nail detachment, surgical exploration is recommended if the hematoma exceeds 50% of the total nail area [17]. However, recent recommendations suggest that, in cases without fracture or with minimal displacement, observation or decompression via trephination is sufficient [18]. In cases where the nail displacement is significant, damage to the adjacent nail bed may occur. Even if the fracture fragment is connected externally, if it remains covered by the nail, there is a risk of future nail deformation or infection. Therefore, the surgeon may choose to remove the nail in order to examine the nail bed and, if necessary, perform the nail bed repair [19]. The removed

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nail may be sutured back to the surrounding tissue after reduction to act as a splint until a new nail grows. In cases of secondary infection due to blood or fluid accumulation beneath the reduced nail plate, moist disinfection is maintained until the sutured nail bed dries, after which the new nail can be expected to regenerate [19].

Shaft Fracture

Fractures of the shaft of the distal phalanx are commonly transverse or longitudinal in nature [20]. When the fracture occurs at the distal attachment of the flexor tendon, a palmar flexion deformity may develop. However, in many cases of shaft fractures, the nail provides anatomical support, resulting in a stable fracture. If there is minimal displacement, surgery is typically not necessary, and a finger splint is applied for 3 to 6 weeks for immobilization. In cases of severe displacement or associated soft tissue injuries, such as damage to the nail bed, surgical intervention may be required. In such instances, the nail is removed, and the nail bed injury is assessed and repaired. The fracture can be stabilized using Kirschner-wires (K-wire). If the fixation provided by the metal pins in the distal phalanx is insufficient, K-wires may be temporarily inserted through the DIP joint for transarticular fixation to stabilize the fracture. In such situations, using relatively small K-wires measuring less than 1.1 inch is recommended to minimize cartilage damage. Once the fracture site has stabilized, the wires can be removed.

Base Fractures

Fractures of the base of the distal phalanx most commonly present as bony mallet finger, where the proximal fragment displaces dorsally. Bony mallet finger occurs when strong axial compression or flexion forces act on the DIP joint while the PIP joint remains extended, causing the proximal fragment, where the extensor tendon inserts, to displace dorsally [21]. A relatively rare mechanism of injury involves hyperextension of the DIP joint, leading to a dorsal impaction of the distal phalanx articular surface against the head of the middle phalanx. In such cases, the remaining distal phalanx may easily dislocate palmarly, often requiring surgical treatment. If left untreated, a bony mallet finger may progress to compensatory hyperextension of the PIP joint, resulting in a swan-neck deformity, or cause joint stiffness or posttraumatic arthritis due to intraarticular fractures. Conservative treatment may be considered when there is no displacement of the bone fragment, less than 30% involvement of the articular surface, and no subluxation of the joint. If the fracture involves 30%-50% or more of the articular surface, instability may occur [22]. Okafor et al. [23] reported on 31 patients with bony mallet fingers treated conservatively, and found that 48% developed arthritis, 29% developed a swan-neck deformity, and an average of 8.3° of DIP joint drooping; however, most patients had satisfactory outcomes. The Cochrane Review also found no significant difference between conservative treatment and K-wire fixation [24]. However, Niechajev [25] recommended surgical treatment when the bone fragment exceeds 3 mm or there is subluxation of the DIP joint. Surgical treatment is most commonly performed using extension block K-wire fixation, first proposed by Ishiguro et al. [26] in 1988 and later modified by various surgeons. Modified techniques include using two extension block pins to equally prevent the extension of the fractured bone fragments [27], or passing a pin through the DIP joint in a diagonal direction or from the palmar side rather than from the fingertip to facilitate fixation [28]. Direct fixation of the bone fragment has also been attempted [29], and methods using dorsal metal pins for fracture reduction and fixation have been introduced (Fig. 1) [30]. While open reduction and other devices, such as small screws, hook plates, or pull-out sutures, have been explored, these techniques are still used sparingly, and there is limited evidence to support their primary use [31].

Jersey fractures, in contrast to bony mallet fingers, are avulsion fractures of the palmarly located base of the distal phalanx caused by the flexor tendon [32]. These injuries typically occur due to sudden hyperextension forces while the DIP joint is actively flexed. The exact mechanism remains debated, but they are common in the fourth finger and often seen in rugby players, hence the name "Jersey" fracture (named after the sports jerseys worn by rugby players) [21]. Unlike bony mallet fingers, which have a contentious indication for surgical treatment, Jersey fractures almost always require surgery. They are classified into five types according to the Modified Leddy and Packer system, based on the degree of displacement of the flexor tendon and the associated distal phalanx fracture [33,34]. In cases with small fragments or no fracture but a true flexor tendon avulsion, proximal migration can occur, even reaching the

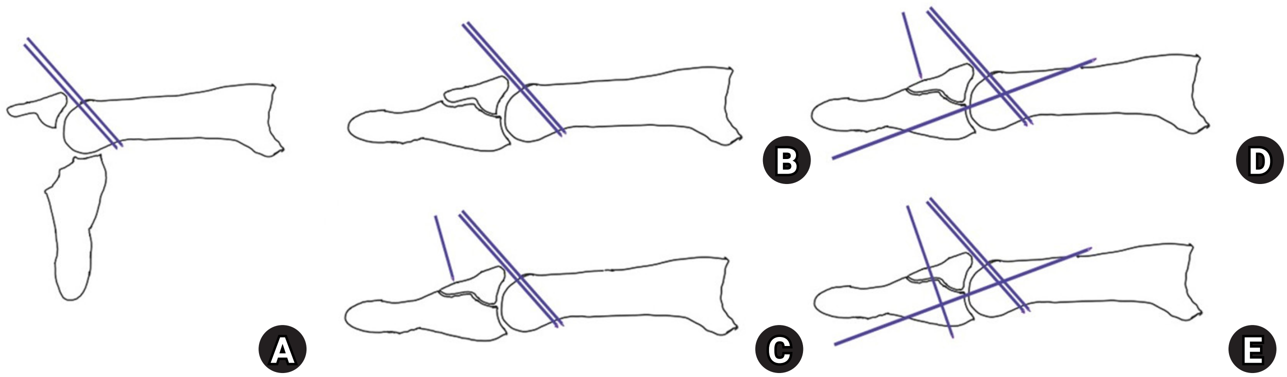

Fig. 1. Modified extension block pinning technique. One or two extension blocking pins are inserted from the dorsal aspect of the proximal phalanx head at around a 45° angle to prevent dorsal fragment displacement (A). Although the distal phalanx segment is extended, the reduction is not perfect (B). With the aid of a dorsal counterforce reduction Kirschner wire (K-wire), an axial transarticular K-wire is inserted from the volar aspect of the distal phalanx (C, D). A dorsal counterforce K-wire is additionally inserted to fix the dorsal fragment in addition to the conventional extension block technique (E).

palm in severe cases (type I). Generally, the dislocation does not extend beyond the palm, from the origin of the palmar lumbricals to the proximal palm. However, if the vincular blood supply is damaged and displacement occurs to the palm (type I), contracture progresses rapidly, and diagnosis and surgery within 7 to 10 days are recommended [21]. Type II, the most common, involves displacement to the PIP joint and is limited by the vincula longus, preventing further displacement. Larger bone fragments may become trapped at the A4 pulley (type III), further limiting displacement.

While rare, Jersey fractures can yield good outcomes with rapid diagnosis, accurate reduction of the flexor tendon or bone fragments, and secure fixation. Preoperative considerations include the degree of proximal tendon displacement, time to diagnosis, and the size of the bone fragment attached to the tendon. Depending on the fragment size, fixation may be performed using screws or pull-out sutures. Recent advances include the use of suture anchors to facilitate tendon attachment repair [35,36]. During active flexion of the DIP joint, forces of up to 28 N are applied, and the load-to-failure strength of pull-out suture fixation is 43 N, while a fine suture anchor can resist up to 69 N [37]. However, the small diameter of the distal phalanx may cause the screw's tip to penetrate the dorsal cortex, potentially irritating surrounding soft tissues such as the nail matrix [38].

In cases where diagnosis is delayed and primary suture repair is no longer feasible, the treatment approach should be discussed with the patient based on their current condition. For injuries involving the fourth or fifth finger, where only limited flexion of the DIP joint is restricted, observation may be sufficient without further treatment. If patients complain of instability in the DIP joint, arthrodesis may be considered. In the second finger, where DIP joint flexion is crucial, tendon grafting or arthrodesis may be considered. However, these options depend on the surgeon's experience, and the results may not always be satisfactory, which should be explained to the patient preoperatively [21,39].

Fractures of the Middle Phalanx and Proximal Phalanx

Head and Neck Fracture

The head of the middle and proximal phalanges are composed of two condyles that form the joint surface at the base of the distal or middle phalanx. The stability of the joint is contributed by the thick palmar plate on the palmar side, the relatively thin joint capsule and extensor tendons on the dorsal side, and collateral ligaments on both sides. Three main types of classification are commonly used based on whether fractures involve the joints and whether displacement occurs [40]. Type I fractures are stable, nondisplaced intraarticular fractures, while type II (unilateral) and type III (bilateral) fractures, which are unstable, require surgical treatment. Depending on the degree of displacement or the size of the fracture fragment, closed or open reduction may be required, and fixation can be

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achieved using metal pins, mini screws, or headless screws. However, it can be difficult to achieve stable fixation when the fragment size is small, and external fixation may be applied in cases of comminuted fractures or joint instability (Fig. 2).

Shaft Facture

Shaft fractures can occur in various patterns, including transverse, oblique, spiral, and comminuted, depending on the type of external force applied. Nonunion is rare, as long as there is no disruption of blood circulation due to soft tissue injury. In the middle phalanx, transverse or short oblique fractures (with fracture lengths less than 2-3 times the diameter of the phalanx) are common, while in the proximal phalanx, oblique or spiral fractures are more frequent [41]. The location of the fracture influences the sagittal finger deformity. In the middle phalanx, fractures occurring distal to the flexor digitorum superficialis insertion lead to apex volar angulation, while those in the proximal region tend to result in apex dorsal angulation. In the proximal phalanx, apex volar angulation is caused by the central tendon on the dorsal side and the intrinsic muscles on the volar side. These deformities are crucial for the surgeon to understand when performing fracture reduction. A shortening of the bone by more than 6 mm or angulation greater than 15° may be considered an indication for surgical treatment, although this is not consistently accepted due to the complexity of the fractures [41]. Furthermore, rotational deformity is considered more important than angulation in the sagittal plane. Rotational deformity is often difficult to assess with X-rays alone, and physical examination is necessary to evaluate whether a rotational deformity is present, helping guide the decision for surgical intervention when needed. The pattern of rotational deformity varies based on the location of the fracture, with fractures in the proximal phalanx having a longer distance to the fingertip compared to the middle phalanx, meaning even a small rotational deformity can have a significant impact at the fingertip.

Base Facture

A base fracture may present as a transverse fracture occurring outside of the joint, though the fracture line originating from the base can extend to an intraarticular fracture or propagate from a shaft fracture, extending to the proximal base. In intraarticular fractures, joint incongruity is a key criterion for surgical treatment decisions, as it can lead to complications such as limited joint ROM and posttraumatic osteoarthritis. These fractures are among the most difficult to treat in hand fractures.

In the case of extraarticular transverse fractures of the proximal phalanx, even if the fracture does not appear severe on X-ray alone, rotational deformity may still be present. Therefore, a diagnosis should not be based solely on X-ray findings, and a thorough physical examination should be performed before surgery to prevent the complication of rotational malunion [9] (Fig. 3).

A common type of base fracture that typically heals without surgical intervention is the avulsion fracture. These fractures are often caused by hyperextension and occur at

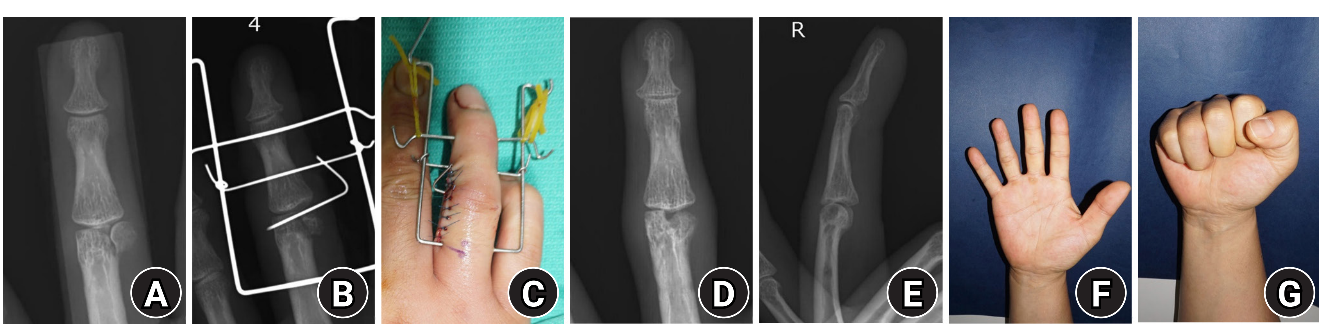

Fig. 2. Distraction dynamic external fixator for displaced condylar fracture of the proximal phalanx. Open reduction was required for a displaced articular fracture involving the condyle of the proximal phalangeal head of the fourth finger (A). Due to the presence of small fracture fragments, the fracture was stabilized using a distraction dynamic external fixator and a temporary Kirschner wire (B, C). Bone union was achieved; however, malunion persisted in the coronal plane (D, E). Despite the malunion, there was no functional impairment of hand movement (F, G).

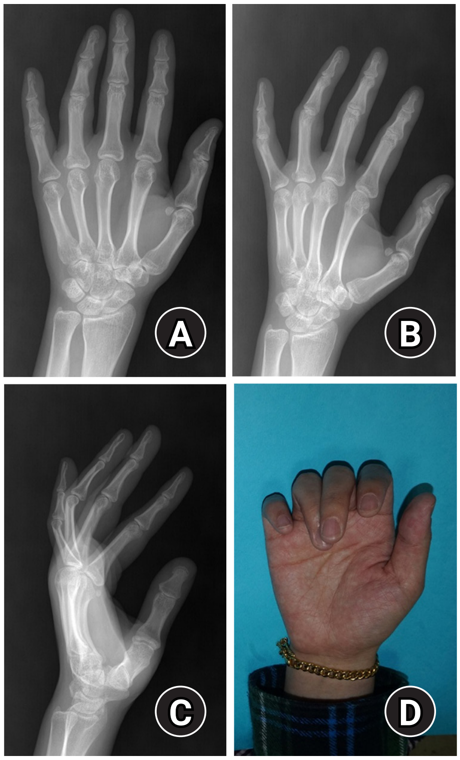

Fig. 3. Proximal phalanx fracture of fourth finger with difference between X-ray findings and physical examination. Fracture of the proximal phalanx base of the fourth finger was shown with minimal displacement on the X-ray (A–C). However, finger overlap due to rotational displacement was observed on physical examination (D).

the base of the middle phalanx, frequently resulting in pain at the PIP joint. Unless there is additional rupture of the collateral ligaments, these fractures typically do not cause joint instability due to the small size of the bone fragments. After pain is controlled with splint fixation, good results can often be achieved with early joint movement [42,43].

The metacarpophalangeal (MCP) joint and PIP joints have collateral ligaments on both sides, providing stability in the coronal plane. When excessive external force is applied, collateral ligament injury may occur. However, avulsion fractures involving the middle or proximal phalanx, including the bone fragments caused by collateral ligament, are common. If the displacement of the bone fragment is less than 2 mm, conservative treatment can be pursued. However, it is more important to assess the joint instability in the coronal plane caused by functional failure of the collateral ligaments than to focus on bone fragment displacement. If instability is not present, conservative treatment using buddy taping or splint fixation is possible [41].

In the case of an intraarticular fractures, subluxation or dislocation may occur simultaneously with displacement of bone fragments. The clinically high incidence and varied treatment outcomes of PIP joint dislocations will be discussed further.

Fractures and Dislocations of the PIP Joint

Compared to the DIP joint, which contributes less to overall finger movement, the PIP joint is a crucial component of finger function. It accounts for approximately 85% of the total ROM, about 100° of flexion and extension [44].

Intra-articular fractures of PIP joint are classified based on the location and characteristics of the bone fragments, such as volar, dorsal, or pilon fractures, as well as direction of dislocation including dorsal, volar, or lateral dislocations. When the size of the intraarticular bone fragments is less than 30% of the joint surface, the fracture is generally considered stable. However, stability decreases as the fragment size increases. If the bone fragment covers more than 50% of the joint surface, instability may occur, requiring surgical intervention [20,43]. If the fracture is stable and the joint surfaces are congruent without signs of subluxation, conservative treatment, such as splint immobilization or buddy taping for 3 to 4 weeks, may be considered. Depending on the direction of instability, the immobilization position can be adjusted to limit either extension or flexion. Regular outpatient follow-up is necessary to monitor potential dislocations or further fragment displacement [43].

The decision to pursue surgical treatment, including the choice of surgical method, should consider factors such as the location and comminution of the bone fragments, as well as the degree of dislocation. Additionally, patient factors such as age and functional needs, and the surgeon's experience, preference, and confidence must also be considered. Several surgical techniques have been reported, including closed reduction with K-wire fixation [45], extension block pinning [46], open reduction and internal fixation [47], external fixation [48], volar plate arthroplasty [49], and hemi-hamate arthroplasty [50]. The precise reduction of intraarticular fragment and secure fixation can promote faster recovery of joint motion and cartilage remodeling, leading to favorable results [43,47,51].

However, prior studies have shown that surgical out-

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comes vary, with some reporting poor results. Finsen [52] reported three cases of postoperative infection, one case of arthrodesis, and one case of amputation among 18 patients treated with Suzuki's pins and rubber traction.

Fracture-dislocations of the PIP joint are most commonly associated with dorsal dislocations following volar fractures [43,47]. Even in the absence of complete dislocation, subluxation can lead to subsequent joint stiffness, emphasizing the importance of accurate diagnosis and appropriate treatment. The "V" sign, observed on lateral radiographs of the middle phalanx, can indicate subluxation when there is widening of the dorsal joint surface. In cases of subluxation, approximately 30° of flexion is possible, however as flexion progresses, instability increases, leading to further dislocation and difficulty in achieving additional flexion, which may require surgical intervention [43]. The author's group has reported favorable outcomes with internal fixation using small-sized plates or screws following fracture reduction via a volar approach in PIP joint dorsal fracture-dislocations (Fig. 4) [44]. If there is significant comminution that makes joint surface preservation difficult, hemi-hamate arthroplasty using the distal hamate articular ridge may be considered (Fig. 5) [50].

Pilon-type fractures occur due to axial compression, leading to intraarticular fragment depression and, additionally, the separation and displacement of volar or dorsal fragments. Instability primarily increases during extension. Given the comminuted nature and displacement of intraarticular fragments, many of these fractures require surgical treatment, which is generally more challenging than other types of fracture displacement [9]. A surgical approach often involves a volar approach to expose the entire base of the proximal phalanx by opening the joint capsule and fully hyperextending the PIP joint to 180° (shotgun approach), though this may result in increased soft tissue dissection. In cases where fracture displacement is not severe, closed reduction and K-wire fixation may be attempted. The depressed articular fragments can be reduced into the proximal phalanx and secured with subsequent K-wires (Fig. 6). Recently, Park et al. [53] reported good outcomes with a technique that does not require joint exposure, in which an extraarticular cortical window is created to perform trans-osseous reduction of the depressed intraarticular fragments, followed by fixation with low-profile locking plates (Fig. 7). This technique results in less soft tissue dissection compared to a volar approach and facilitates easier reduction of the articular fragments, ultimately enabling early joint mobilization through locking plate fixation.

Volar dislocations are relatively rare and are often associated with the attachment of the central slip to the dorsal

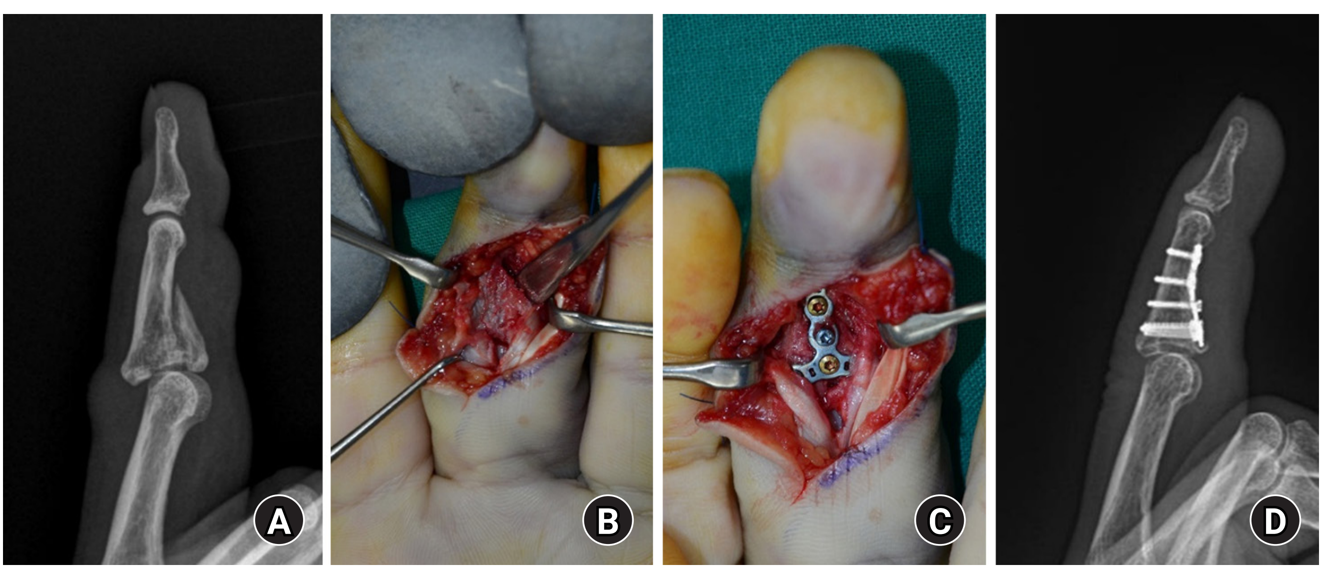

Fig. 4. Fracture of the base of the middle phalanx with dorsal subluxation. Subluxation of the proximal interphalangeal joint was caused by a basal fracture of the left third middle phalanx (A). The articular surface was reduced, and plate fixation was performed through a volar approach (B, C). The fracture surface was successfully reduced, and the subluxation was corrected (D). Case courtesy of SH Han from CHA University, Seongnam, Korea.

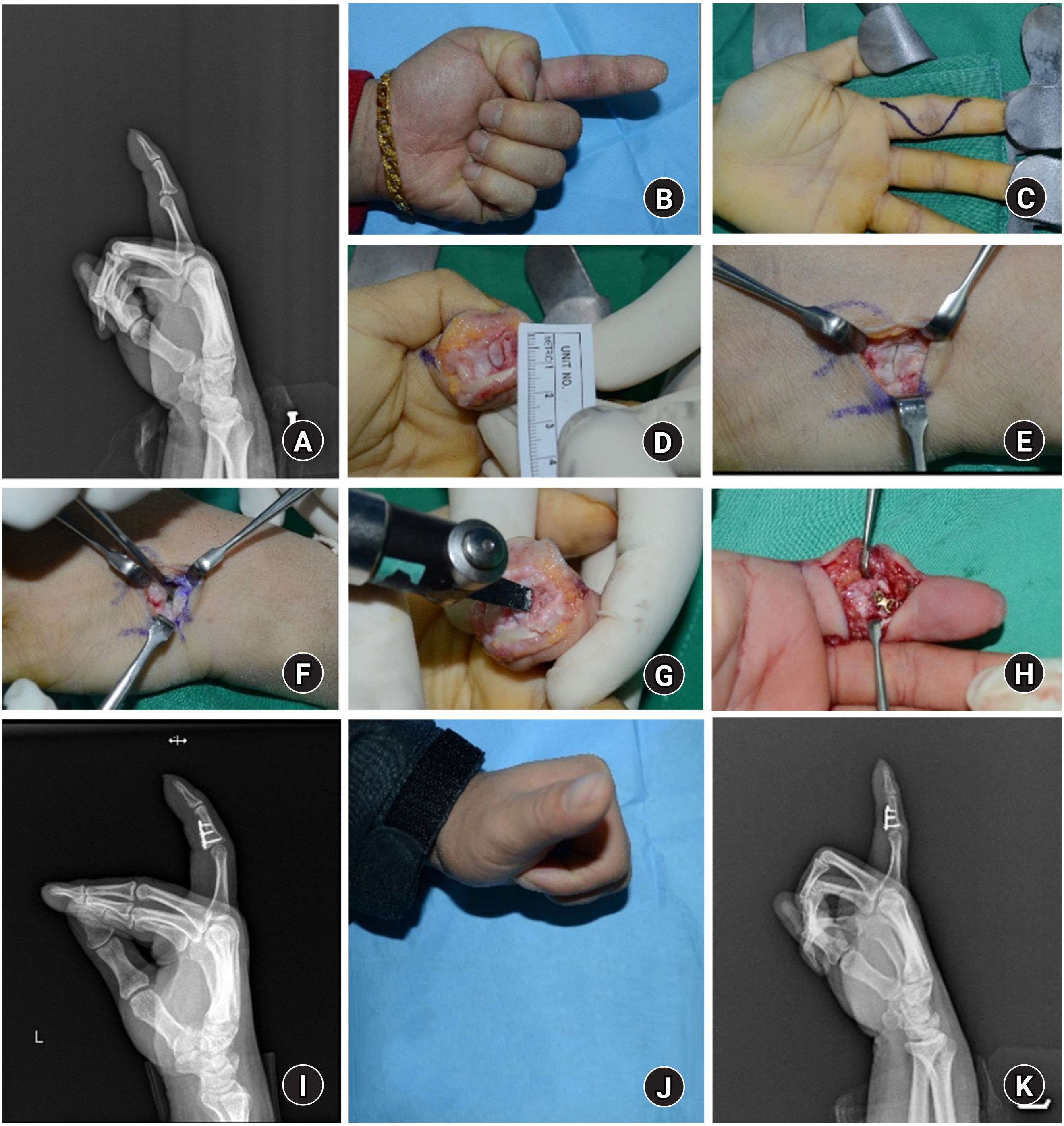

Fig. 5. Hemi-hamate arthroplasty. Lateral plain X-ray presented middle phalanx base volar comminuted fracture and dorsal subluxation of joint (A). The patient complaint limited flexion in preoperative clinic (B). Volar Bruner incision was designed (C) and the fractured site was visualized with shot-gun approach (D). After fracture fragment measurement, dorsal hamate-metacarpal joint is approached for hemi-hamate harvest (E, F). With fractured proximal phalanx base preparation, the harvested hamate bone was grafted and fixed with small sized plate and screws (G, H). Post operatively harvested bone well fixed with implant without joint subluxation (I). On 8 months of post-operation, patient recovered full flexion without arthritic change (J, K). Case courtesy of SH Han from CHA University, Seongnam, Korea.

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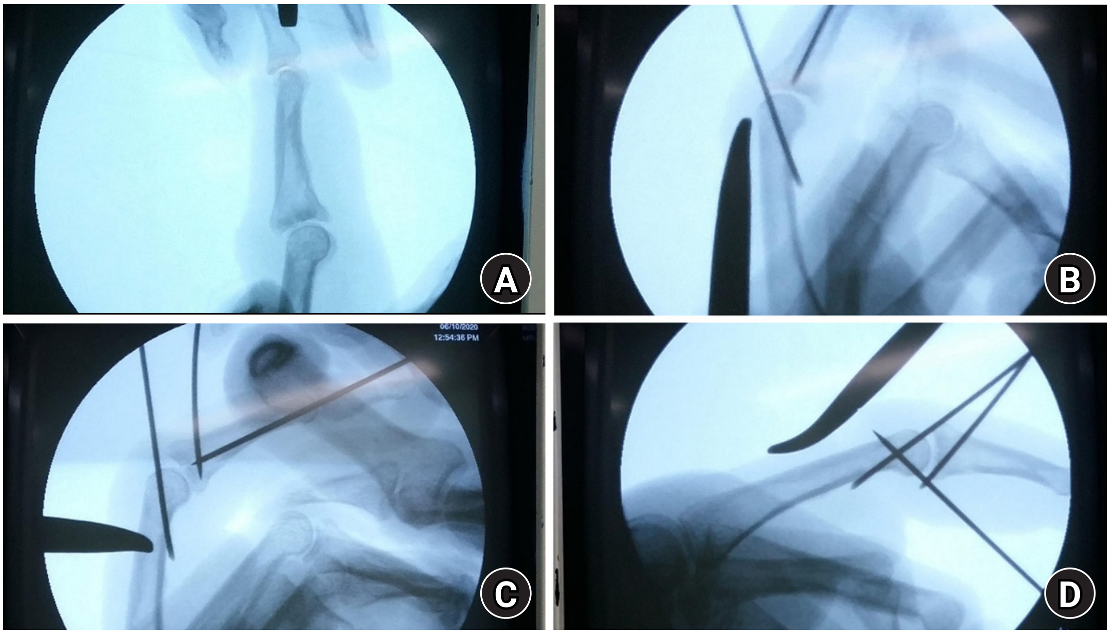

Fig. 6. Closed reduction and K-wire fixation for depressed articular fragment and dorsal subluxation. In lateral C-arm image intensifier, middle phalanx articular fragment depressed and dorsal joint subluxation was identified (A). With extension blocking pin inserted, the depressed joint fragment reduced using intramedullary K-wire by closed method (B). Additional inter-fragment K-wire inserted from dorsal aspect in properly reduced position (C). Finally, additional volar flexion blocking pin was inserted (D).

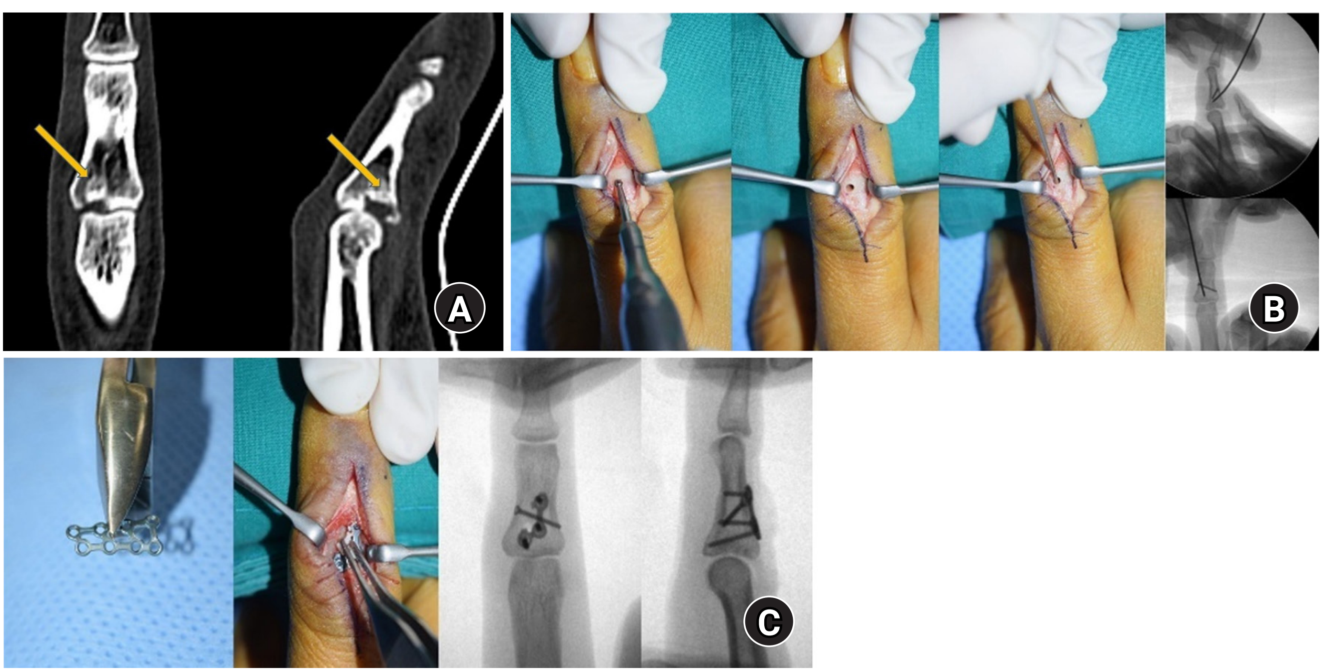

Fig. 7. A representative case of trans-osseous reduction and dorsal locking plate fixation. A preoperative computed tomography scan presented a volar lip fracture with a depressed intra-articular fragment (arrows) (A). Cortical window creation on the dorsal bare area of the middle phalanx, and reduction of the impacted fragment using a Kirschner-wire inserted through the window (B). Locking plate positioning after reduction and insertion of the most proximal screw to buttress the articular fragment (C). Case courtesy of JW Park from Korea University, Seoul, Korea.

fragment. If inadequately treated, they can result in extension lag of the PIP joint, and over time, the conjoint lateral band may shift volarly, causing hyperextension of the DIP joint and leading to a boutonniere deformity. When instability increases during flexion, when the fragment comprises more than 50% of the joint surface, or when extension is restricted or dislocation is observed during flexion, surgical treatment is indicated (Fig. 8).

Surgical Treatment

As noted previously, the decision-making factors for surgical treatment include the presence of intraarticular fractures, the stability of the fracture, and the degree of soft tissue injury. Additionally, patient-related factors, such as high physical activity levels, occupations that require heavy use of the hands, and the dominant hand, are also considered. In such cases, more robust fixation and early rehabilitation are often prioritized. Based on the location and pattern of the fracture, a computed tomography scan is performed to assess the need for surgery and establish a surgical plan. In addition to the traditional methods of closed reduction and K-wire fixation, various other surgical techniques are available. The surgeon should select the most appropriate method based on familiarity and expertise, considering the fracture characteristics and the patient's individual factors [9].

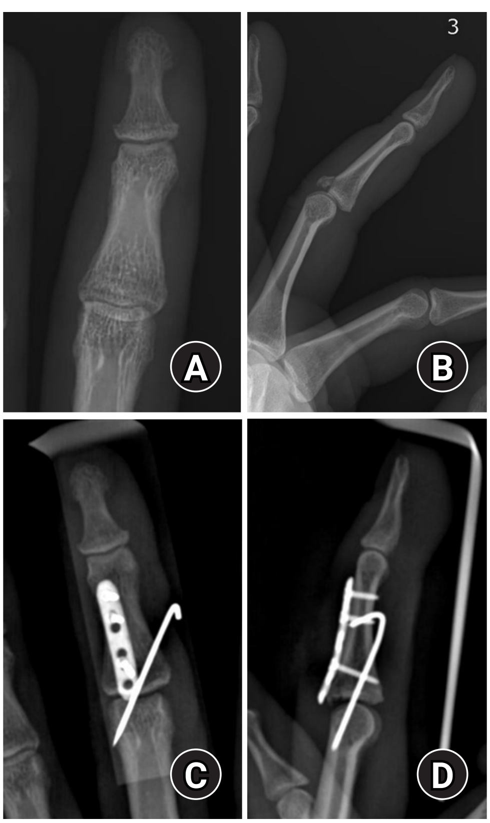

Fig. 8. Middle phalanx base fracture and subluxation. Subluxation of the proximal interphalangeal joint was caused by a fracture of the base of the right third middle phalanx (A, B). Fractures and subluxations were reduced by dorsal plating and temporary K-wire fixation (C, D).

K-wire vs. Plate Fixation

The most commonly used fixation method for hand fractures is K-wire fixation. Typically, after closed reduction, K-wires are percutaneously inserted, and once the fracture site is stabilized, the pins are removed [5,54]. Although complications such as pin migration, loss of fracture stability, skin irritation, and potential infection may occur, these are relatively uncommon. According to Hsu et al. [54], the reported infection rate is 7%, most of which are superficial and rarely progress to osteomyelitis or pyogenic arthritis. The main advantage of K-wire fixation over plate fixation is the reduced risk of additional soft tissue damage, as well as the avoidance of adhesions between bone and tendon, which can lead to joint stiffness. Additionally, there is no need for secondary surgery to remove the plate, making K-wire fixation the preferred choice [55]. The inserted K-wires are typically removed at postoperative 10 to 28 days after insertion, depending on the fracture pattern, patient factors, and the surgeon's experience [9].

In cases where K-wire fixation alone cannot provide adequate stability, plate fixation may be used selectively. The type of plate (e.g., compression, tension band, bridge, or neutralization plate) depends on the method used to fix the fractures. When using plate fixation, it is essential that the screws do not penetrate beyond the distal cortex, to avoid causing damage to surrounding structures such as tendons, nerves, or blood vessels. After achieving stable fixation with the plate, early joint motion is encouraged. The skin incision and soft tissue dissection required for fracture reduction and plate fixation, as well as adhesions caused by the plate itself, can lead to joint stiffness, which is a significant disadvantage of plate fixation [9]. Depending on the surgeon's preference, some studies report better clinical outcomes with plate fixation compared to K-wire.

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Additionally, robust mini and low-profile metal plates with superior fixation strength have been introduced, reducing the impact on the surrounding soft tissues of the hand [12,41,56]. Recent studies have also compared the use of bioabsorbable miniplates for metacarpal fractures with conventional metallic plates [57].

Screw Fixation

Screws smaller than 2 mm can be used for fragment fixation following either closed reduction or open reduction, utilizing lag screw or neutralization screw techniques. This method is commonly used for simple oblique fractures and provides intermediate stability between K-wire and plate, making it stable enough for early rehabilitation without causing irritation from the fixation device. However, this method is difficult to apply in cases of comminuted or transverse fractures, and the risk of causing additional fractures during screw insertion may arise if the bone fragments are small. In a prospective study by Horton et al. [58], comparing the closed reduction with K-wire fixation and open reduction with lag screw fixation for spiral or oblique fractures of the proximal metacarpal, no significant functional or radiological differences were observed between the two groups.

Recently, an intramedullary fixation technique using headless screws has been attempted following its initial introduction in 2010 by Boulton et al. [59] The use of headless screws for intramedullary fixation offers advantages such as a small incision (2–3 mm), high stability, minimal damage to the periosteum surrounding the fracture, and reduced soft tissue irritation from the fixation device, while also allowing direct compression of the fracture site [60]. This method is most suitable for extraarticular transverse or short oblique shaft fractures, and it can also be applied to base fractures, comminuted fractures, and open fractures [60]. However, it is absolutely contraindicated in cases of active infection or open growth plates, and caution should be exercised in the case of intraarticular fractures, long oblique fractures, and subchondral fractures [61].

The surgical technique can be divided into antegrade and retrograde insertion depending on the direction of screw insertion. The antegrade approach includes two methods: the intraarticular approach, which accesses only the joint surface of the proximal metacarpal base, and the transarticular approach, which passes through the metacarpal head to fix the fracture [62-64]. The intraarticular method is more commonly used [60].

The single headless screw fixation method, using the longest and thickest screw to stabilize the fracture, is often preferred. This method provides adequate fixation for simple fractures, such as transverse or short oblique shaft fractures. However, the fracture pattern can pose significant risks. In comminuted neck fractures, excessive compression from the headless screw may lead to bone shortening. Additionally, due to the relatively larger diameter of the medullary canal compared to the screw, fixation at the metaphysis may be inadequate, often necessitating the insertion of additional screws [62,65].

Wide-awake Local Anesthesia No Tourniquet

Wide-awake local anesthesia no tourniquet (WALANT) is a technique that uses a local anesthetic composed of 1% lidocaine, 1:100,000 epinephrine, and 8.4% bicarbonate to achieve both anesthesia and hemostasis simultaneously [66]. This technique was organized and popularized by Lalonde et al. [67], and has been widely applied in hand surgery. Since WALANT does not require a tourniquet, it avoids the pain associated with tourniquet use and allows for real-time assessment of hand function during surgery. This makes it particularly useful for tendon surgeries and has also been increasingly applied in hand fracture surgeries [67]. However, its effectiveness in finger fractures may be limited because, even before WALANT, local anesthesia was sufficient for performing surgery while assessing joint motion. Additionally, a finger tourniquet can create a bloodless field without the need for epinephrine. Although WALANT theoretically has broad applicability for all local anesthesia surgeries in hand fractures, it is considered particularly useful in cases where a finger tourniquet is difficult to apply, such as with fractures of the proximal phalanx shaft or base.

Complications

Stiffness

Stiffness is the most common complication following hand fractures [11,56]. It can affect not only the injured finger but also adjacent digits or even the entire hand [41]. Contributing factors include swelling and soft tissue damage resulting from trauma, infection, surgery-induced injury, or vascular dysfunction [56,68]. Notably, prolonged immobilization—regardless of whether surgery was performed—is strongly associated with stiffness [11]. In the past, some physicians believed that refraining from finger joint motion for up to 6 to 8 weeks, until the late 1970s, was the best approach for healing [51]. However, joint stiffness resulting from prolonged immobilization can cause pain and burden for both the patient and physical therapist during rehabilitation, and in some cases, secondary surgeries such as capsular release or tenolysis may be required. These secondary procedures, however, do not always yield optimal results.

Early joint motion can help alleviate swelling and reduce stiffness [11,68]. Musculoskeletal tissues require adequate movement and stress to maintain health. The timing and method of initiating joint motion depend on the fracture pattern and fixation technique, and therefore, there are no standardized guidelines. In the case of unstable fractures, it is necessary to provide rigid fixation followed by early mobilization [69]. Generally, radiographic stability with callus formation is observed several weeks after achieving real fracture site stability, so it is recommended to begin joint motion around 2 to 4 weeks after pin removal [9].

The immobilization position is also important. A common limitation in finger motion occurs in the MCP joint, where flexion is often restricted due to the "cam effect", while in the PIP joint, extension is more frequently limited. For hand fractures, preventing future finger stiffness is best achieved by immobilizing the MCP joint at 50°–70° of flexion and the PIP joint from 15° to full extension, thereby maintaining the intrinsic positive position [8].

Malrotation

Malrotation and malunion in the coronal plane tend to result in poorer outcomes compared to sagittal plane malunion, as overlap between the fingers due to malunion can lead to significant functional impairments [56]. No standardized method currently exists to objectively assess the degree of rotational alignment in the fingers for guiding corrective surgery. With MCP and PIP joint flexion, finger overlapping or scissoring is regarded as malrotation [70-72]. Furthermore, on this position, second to fifth ray fingertip point can converge to scaphoid tubercle [72,73], which may warrant reoperation [74]. Therefore, malunion should be assessed early in the course of fracture healing or immediately after surgical fixation. Under general anesthesia, when active finger flexion is not possible, passively extending the wrist causes the fingers to flex due to the tension in the flexor tendons. This maneuver helps detect any overlap between the fingers, which may indicate a rotational deformity.

Nonunion

Nonunion of phalangeal fractures is uncommon, with a reported incidence of around 1% [56]. Factors that influence fracture healing include the fracture pattern including bone loss, stability, soft tissue damage such as open fractures, vascular injury, and fixation in a distracted fracture site. Although it may take considerable time to confirm fracture union and radiographic fracture lines can be visible for as long as 1 year, clinical signs and symptoms such as instability, gross deformity, implant failure, and persistent pain are far more important in determining nonunion [56].

While radiographic nonunion does not always lead to clinical complications, intervention is required when symptoms such as pain are present. Treatment options include osteosynthesis with bone grafting, arthrodesis, and amputation [7]. When osteosynthesis is attempted, careful preparation of the fracture ends is essential. Fenestration drilling can promote endosteal circulation at the fracture site, followed by placement of bone grafts in the prepared space. Although the fixation techniques used to restore normal anatomy in cases of nonunion are similar to those used for primary fracture treatment, it is advisable to pursue more stable fixation.

Conclusions

The goal of treatment for hand fractures is to maintain the normal alignment of the fractured finger, achieve a pain-free state, and restore the full ROM to ultimately return the finger to its pre-injury condition. The treating physician decides between conservative and surgical treatment. When conservative treatment is chosen, decisions must be made regarding immobilization methods and the timing for initiating joint motion, and it is necessary to monitor any displacement through outpatient follow-up. When surgical treatment is chosen, it is important to understand the characteristics of the fracture to determine how to approach fracture fixation and which method to use. Postoperatively,

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it is essential to check for infections at the surgical site and for any displacement of the fixation, while reducing the risk of stiffness through ROM exercises at the appropriate time.

Article Information

Author contributions

Conceptualization: HTK, JKL. Formal analysis: JKL. Methodology: HTK. Project administration: JKL. Supervision: JKL. Validation: HTK, JKL. Writing-original draft: HTK. Writing-review & editing: JKL. All authors read and approved the final manuscript.

Conflicts of interest

Jun-Ku Lee is an editorial board member of the journal but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflicts of interest relevant to this article were reported.

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Data availability

Not applicable.

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Atypical ulnar fractures: a narrative review of current concepts and a case of bilateral surgical management

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Atypical ulnar fractures (AUFs) are rare complications that are often linked to long-term antiresorptive therapy. Although atypical femoral fractures are well-studied, AUFs lack standardized diagnostic and treatment protocols. This review summarizes current knowledge on AUFs, including their pathophysiology, diagnostic criteria, and management. A case of bilateral AUFs treated with two distinct osteosynthesis methods is presented, emphasizing the principles of biological healing and mechanical stabilization.

Keywords: Ulnar fracture; Bisphosphonates; Internal fracture fixation; Bone graft; Teriparatide

Introduction

The use of antiresorptive agents, primarily bisphosphonates, in the management of osteoporosis has led to emerging complications that require attention from medical professionals. One such complication is atypical fractures resulting from decreased bone formation and suppressed bone remodeling.

While early recognition of these fractures has predominantly focused on femoral shaft or subtrochanteric fractures, orthopedic surgeons have increasingly recognized atypical ulnar fractures (AUFs) occurring in the proximal ulna since the first report in 2011 [1], albeit with a limited number of case reports and literature reviews available to date [2,3]. Although much rarer, bilateral AUFs have also been reported [4,5].

Unlike typical ulnar fractures, which often respond well to open reduction and plate fixation, the same treatment approach as typical ulnar fractures may result in failure when applied to AUFs [4,6,7]. Nonetheless, a definitive therapeutic strategy has yet to be established due to the rarity of their occurrence. Recent clinical reports advocate for osteosynthesis techniques involving bone grafting for better outcomes [2,7].

This study aims to comprehensively review the clinical characteristics, diagnostic approaches, and therapeutic strategies for AUFs based on the existing literature, and to introduce cases of bilateral AUFs and describe our surgical treatment for osteosynthesis, which included the use of autologous iliac bone grafts. Importantly, we note that the specifics of our surgical techniques differed between the right cortical and left cancellous bone graft. This article provides a narrative review of current concepts in AUFs and illustrates them through a representative bilateral case.

Review Article

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Pathophysiology

Several studies have demonstrated an association between bisphosphonate therapy and the occurrence of atypical femoral fractures (AFFs) involving the femoral shaft or subtrochanteric region [8-10]. Prolonged suppression of bone turnover and remodeling due to long-term bisphosphonate exposure has been shown to result in the accumulation of microdamage within the bone [8,11]. Over-suppression of bone turnover resulting from prolonged bisphosphonate therapy has been reported to reduce bone elasticity, increase resistance to plastic deformation, and decrease resistance to crack propagation, thereby contributing to the development of atypical fractures [12,13]. Tensile stress generated by axial loading has been identified as a biomechanical factor contributing to the development of fractures [14]. The AUFs have been understood to occur through mechanisms similar to those proposed for AFFs. The interosseous membrane of the forearm serves as a critical longitudinal stabilizer, preserving forearm function and facilitating load transmission between the radius and ulna [15]. A finite element analysis study demonstrated that the maximum tensile stress, measured at 7.769 MPa at 64.6% of the total ulnar length (153.4 mm of 237.5 mm from the ulnar head), was generated by a combination of axial loading on the ulna, proximal traction by the triceps brachii and anconeus muscles, and distal traction by the interosseous membrane of the forearm [16]. Tensile stress, generated and transmitted by the interosseous membrane—a ligamentous complex in the forearm—plays a key role in the development of fractures [17]. The dorsal oblique accessory cord (DOAC) is a robust fibrous structure, whereas the proximal oblique cord (POC) has minimal functional significance in humans [18]. the DOAC is thought to prevent distal displacement of the radius while exerting a distal traction force on the ulna, with cadaveric studies reporting that the insertion points of the DOAC and POC are located at 61.8%–64.0% of the total ulnar length from the ulnar head, and the maximal tensile stress has been observed to occur between these two structures [15,16,19]. The maximal tensile stress occurs between the DOAC and the POC, generated by the opposing forces of the triceps brachii and anconeus muscles pulling the ulna proximally and the DOAC exerting a distal traction on the ulna, and this stress concentration may be further augmented by the anatomical feature wherein the proximal part of the middle portion of the interosseous membrane consists of a transparent membranous tissue with a perforation for the interosseous artery, leaving the ulna at that level partially unsupported (Fig. 1) [16].

Diagnosis

In their 2013 report, the American Society for Bone and Mineral Research (ASBMR) Task Force revised the case definition of AFFs based on accumulated clinical and radiographic evidence [20]. The revised definition refined the major features by specifying radiographic characteristics, including fracture location along the femoral diaphysis, a transverse or short oblique fracture orientation, minimal or absent comminution, and localized periosteal or endosteal thickening of the lateral cortex [20].

The diagnostic criteria for AUFs were derived from those established for AFFs. Heo et al. [21] subsequently modified the 2013 case definition proposed by the ASBMR Task Force to create a case definition for AUFs by incorporating the aforementioned differences (Table 1).

The diagnostic criteria for AUFs were adapted from those for AFFs by modifying the fracture location to correspond to the ulnar diaphysis. It was proposed that at least four of the five major features must be present for diagnosis, while minor features are not required but may be associated findings. In addition, "previous history or present symptom

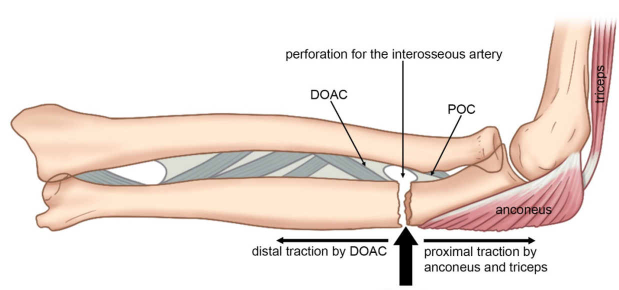

Fig. 1. Anatomical structures related to tensile stress distribution in the proximal ulna. The dorsal oblique accessory cord (DOAC), a robust fibrous structure, inserts at 61.8%–64.0% of the total ulnar length and exerts a distal traction force on the ulna, opposing the proximal pulling forces of the triceps brachii and anconeus muscles. Maximal tensile stress is concentrated between the DOAC and the proximal oblique cord (POC), where a perforation in the proximal portion of the interosseous membrane leaves the underlying ulna partially unsupported. AUF, atypical ulnar fracture.

Table 1. Modified case definition for atypical ulnar fractures

Variable	Revised definition
Fracture location	The fracture must be located on the ulnar diaphysis between 20% and 45% distal to the olecranon tip.
In addition	At least 4 of 5 major features must be present. None of the minor features are required but they have sometimes been associated with these fractures.
Major features	
M1	The fracture is associated with minimal or no trauma, as in a fall from a standing height or less.
M2	The fracture line originates at the posterior cortex and is substantially transverse in its orientation, although it may become oblique as it progresses anteriorly across the ulna.
M3	A complete fracture extends through both cortices and may be associated with an anterior spike; an incomplete fracture involves only the posterior cortex.
M4	The fracture is noncomminuted or minimally comminuted.
M5	Localized periosteal or endosteal thickening of the posterior cortex is present at the fracture site.
Minor features	
m1	Diffuse cortical thickening of the whole cortex is present at the fracture site.
m2	Unilateral or bilateral prodromal symptoms such as dull or aching pain in the forearm.
m3	Bilateral incomplete or complete ulnar diaphysis fractures.
m4	Delayed fracture healing.
m5	Previous history or present symptom of atypical femoral fractures.

of atypical femoral fractures" was added as a new minor feature (m5), reflecting the frequent coexistence of AFFs in patients with AUFs [21].

Treatment Strategies

Medical Strategy

To prevent atypical fractures, it has been suggested that the risk of AFFs decreases by more than 50% within the first year after discontinuation of oral bisphosphonate therapy and by over 80% after 3 years, supporting the practice of implementing drug holidays approximately every 5 years during long-term bisphosphonate treatment [22].

Several studies have reported favorable outcomes with the use of teriparatide for the healing of atypical fractures. Carvalho et al. [23] demonstrated that in three postmenopausal women with osteoporosis who sustained atypical subtrochanteric or femoral shaft fractures without major trauma during long-term bisphosphonate therapy, treatment with teriparatide resulted in significant increases in bone turnover markers and radiographic evidence of fracture healing within a few months.

Preclinical studies have also reported favorable effects of teriparatide treatment for AFFs. In five women with AFFs, 6 months of teriparatide therapy significantly increased the expression of mesenchymal stromal cell markers (CD73, CD90, and CD105), upregulated pluripotency-related genes (notably *NANOG*), enhanced cellular proliferation, reduced cellular senescence, and improved both osteogenic and adipogenic differentiation. These findings suggest that teriparatide may rejuvenate bone marrow mononuclear cells, thereby promoting bone regeneration and indicating broader therapeutic potential [24].

For the management of incomplete AFFs, Feron et al. [25] proposed a treatment algorithm. When cortical radiolucency is present, conservative management including limited weight-bearing, calcium and vitamin D supplementation, and teriparatide therapy is recommended. Healing should be reassessed after 3 months; if clinical symptoms have resolved, radiographic healing is evident, and magnetic resonance imaging (MRI) demonstrates no bone edema, continued observation. However, if a radiolucent line persists or if there is no clinical or MRI improvement, prophylactic intramedullary nailing should be considered to prevent progression to complete fracture. Although a standardized treatment protocol for AUFs has not yet been established, it is reasonable to speculate that a management algorithm similar to that for AFFs may be applicable.

Although the evidence regarding the efficacy of vitamin D and calcium supplementation in promoting the healing of atypical fractures remains inconclusive and somewhat controversial, multiple studies recommend their administration as part of the overall management strategy during conservative treatment [20,21,25-27]. In the management

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of patients with AUFs, vitamin D and calcium supplementation should not be used as standalone therapies but rather as adjunctive measures in conjunction with other treatment modalities.

Although rarely reported, other antiresorptive agents such as denosumab can also lead to AUFs by inhibiting bone resorption, altering bone turnover, and increasing bone mineral density [3,28,29]. While further research is needed, clinicians are advised to maintain a high index of suspicion for AUFs in patients receiving denosumab who present with relevant clinical symptoms and radiographic features.

Case Report and Plan to Surgical Treatment Strategy

Case

An 81-year-old female patient sustained injuries to both of her forearms while leaning forward near the tap and subsequently visited the emergency room. She required a cane for outdoor ambulation and had a medical history of cardiac valvular disease. Additionally, she had been prescribed ibandronate by her local hospital for the past 15 years to manage osteoporosis.

Upon initial X-ray examination, minimal displaced transverse and short oblique fractures were observed in both proximal 1/3 ulna (Fig. 2). Additionally, both fracture margins exhibited sclerotic changes with approximately 5 mm thickness at both fracture ends, which were consistent in both forearms. Computed tomographs revealed cortical bone thickness at the fracture site, with a loss of cancellous bone filling in the medullary canal, and cortical thickness on both sides of the fracture section measuring 4 to 5 mm (Fig. 3). Under general anesthesia, we attempted osteosynthesis using a bone graft harvested from the patient's right iliac bone, following complete resection of pathologic nonviable cortical bone.

Fig. 2. Initial X-ray images of both forearms. Right forearm (A). Left forearm (B).

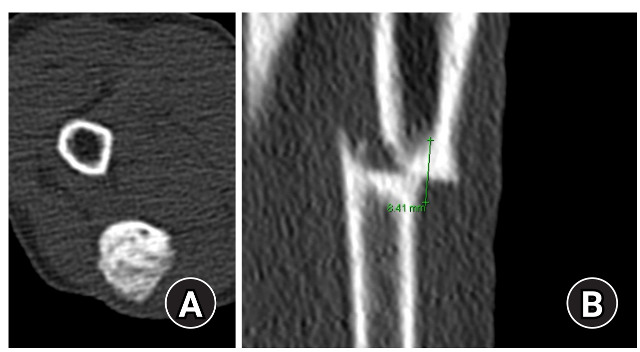

Fig. 3. Axial computed tomography image at the level of sclerotic bone lesion without medullary canal (A). The length of both sclerotic margin ends was over 8 mm (B).

Right forearm

The fracture site was easily identified on the surface due to skin protrusion (Fig. 4A). We performed a direct ulnar approach between the extensor carpi ulnaris and flexor carpi ulnaris muscles. Using an oscillating saw, we resected a 4 mm thickness of cortical bone in each, resulting in an 8-10 mm gap between the proximal and distal segments (Fig. 4B). We harvested a tricortical bone graft over 20 mm in size from the right iliac crest, intending to use 10 mm of harvested bone in each forearm (Fig. 4C). The graft was halved, and a 10 mm tricortical bone segment was inserted into the resected ulnar gap. The fracture site was then tapped to push it into the defect site (Fig. 4D). Subsequently, we applied a 10-hole 3.5 mm limited contact locking compression plate (LC-LCP), securing four screws in each

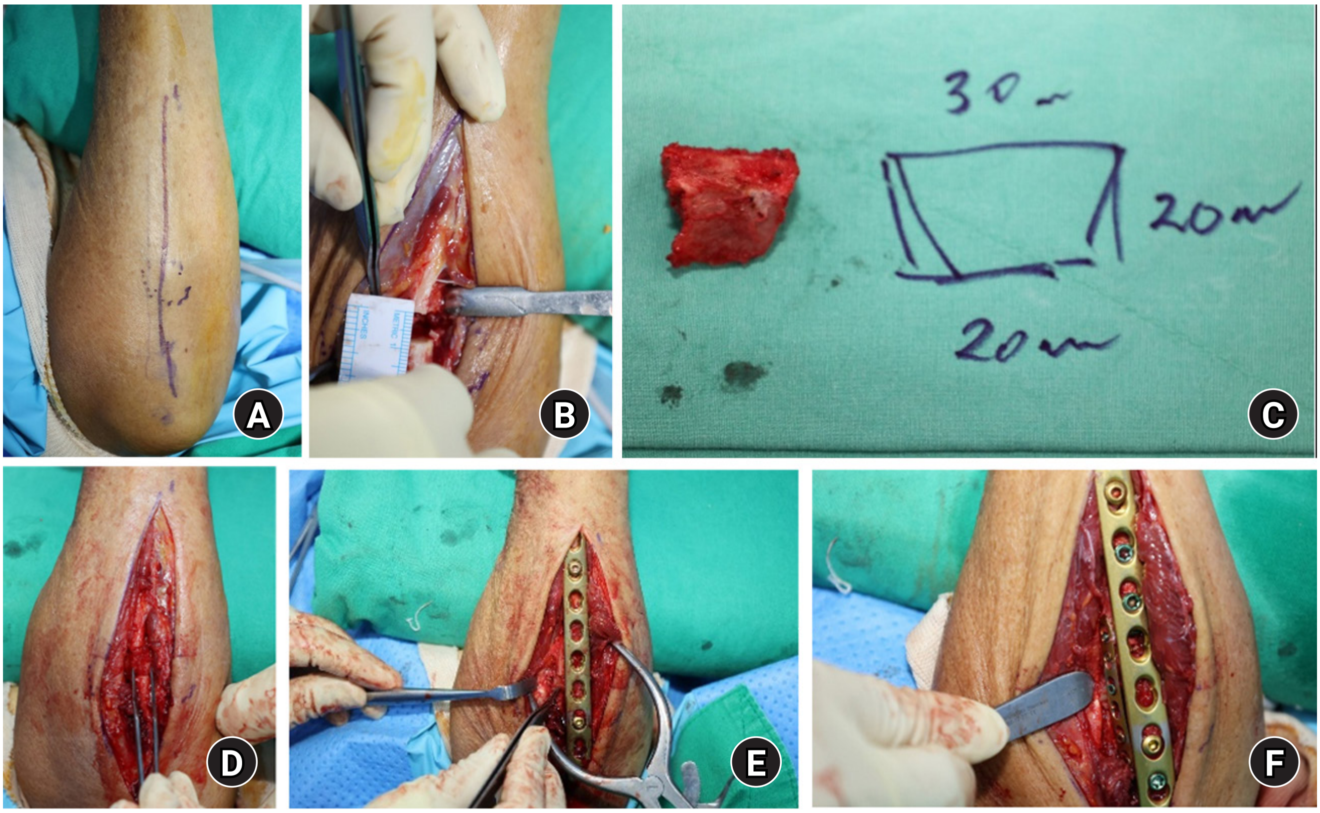

Fig. 4. The protruding atypical ulnar fracture was visible overlying skin (A). The overall gap created by resecting the sclerotic margins of both bone segments measured approximately 9 mm (B). Tricortical bone exceeding 20 mm in length was harvested from the right iliac crest (C). Half of the cortical bone was inset into the defect site (D). The 3.5 mm limited contact locking compression plate fixation (E). Additional 2.0 mm small plate augmentation at the lateral aspect of ulna (F).

segment (Fig. 4E). Additionally, a 2.0 mm small fragment plate was attached to hold the harvested bone at a 90° angle to the main plate (Fig. 4F).

Left forearm

Initially, we attempted to apply the same procedures to the left forearm. However, the remaining 10 mm length hard tricortical bone broke during tapping into the gap created by the same 4-5 mm resection in each fracture segment. Consequently, we modified our original plan, reducing the fracture site until the defect was closed, leaving a 4 mm gap before plate fixation. We applied a 3.5 mm LC-LCP and fixed proximal four screws and distal three screws above and below gap remaining. Additionally, we harvested cancellous bone from the initial iliac crest and inserted it into the defect site. The original cortical bone was further chopped and inserted into the defect area also. To provide further strength, we also applied a 2.0 mm small fragment plate, similar to the approach used for the right arm.

Postoperative and follow-up management

Postoperatively, the bone-grafted gaps measured 9.5 mm and 3.8 mm in the right and left forearms, respectively (Fig. 5). Additionally, we conducted elbow and wrist X-rays, which revealed a positive ulnar variance of 3 mm in the right wrist and a negative variance of 2 mm in the left wrist (Fig. 6). Both wrists exhibited ulnocarpal impaction lesion in both lunates.

We discontinued ibandronate medication and initiated treatment with bone-forming and parathyroid hormone agents. Both femurs were examined to check for atypical femur lesions, yielding negative results. Bone mineral density evaluation showed T-scores of -3.8 and -2.3 in the average lumbar spine and femur neck areas, respectively.

A short arm splint, long enough to cover the fracture site yet allowing for elbow motion, was applied for 2 weeks

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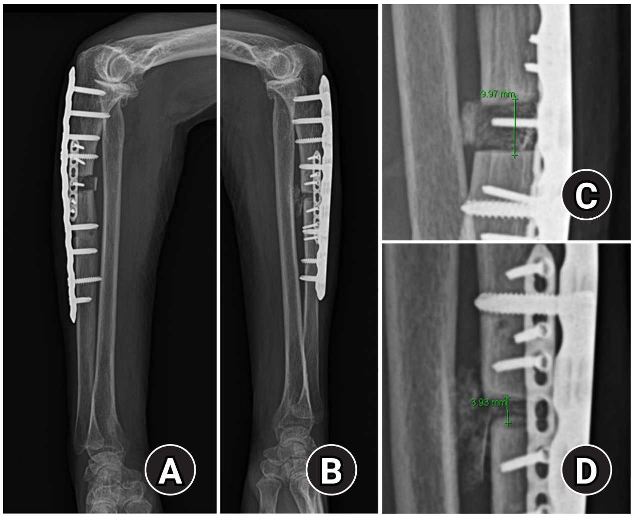

Fig. 5. Postoperative lateral plain X-rays of the right (A) and left (B) forearms. The gaps were measured as 9.9 mm on the right (C) and 3.9 mm on the left (D).

Fig. 6. Postoperative anteroposterior wrist X-ray showing positive and negative ulnar variance. (A) Right wrist. (B) Left wrist.

postoperatively. Given sustained fixation stability with the implant, we permitted elbow and wrist range of motion with intermittent removable brace protection.

Serial X-ray follow-ups were conducted at postoperative intervals of 1 week, 2 weeks, 4 weeks, 8 weeks, and 20 weeks, and thereafter. At the 20-week outpatient follow-up, the patient reported being free of pain at both forearm fracture sites, and both forearms showed complete union without any visible fracture lines (Fig. 7). For long-term follow-up, we contacted the patient's daughter by phone. She stated that the patient did not return to the outpatient clinic primarily because she had no symptoms and was able to maintain a full range of motion. Furthermore, the patient resides a considerable distance from the hospital, and she was recently diagnosed with lymphadenitis, which may be associated with cancer metastasis.

The patient and the patient's daughter provided consent for the publication of this case report, including all clinical images.

Case discussion

AUFs represent a distinct subset of ulnar fractures characterized by their unique presentation and etiology. Unlike typical ulnar fractures, AUFs occur spontaneously or with minimal trauma. Prolonged bisphosphonate use can induce microstructural changes in bone tissue, predisposing it to atypical fracture patterns under minimal or spontaneous loading.

To date, only a limited number of case—around 40—have reported on AUFs, and treatment principles have not been firmly established [2,6]. Though it is inconclusive in terms of operative treatment strategy, the classic approach of open reduction and internal fixation used in typical ulnar fractures carries a risk of treatment failure [7]. Nonsurgical treatment of AUFs had a high risk of nonunion. Incomplete or nondisplaced complete fractures that were treated non-surgically eventually progressed to complete displaced fractures and nonunion [14,27,30].

In terms of fracture healing through osteosynthesis, two main principles must be considered: biology and fixation stiffness. Addressing the biology aspect, the sclerotic bone margins at the fracture ends were deemed nonviable lesions, prompting us to resect them completely until normal cancellous bone canal appeared. After sufficient resection, the resulting gap necessitates bone grafting to facilitate the formation of new healthy bone in the gap area. Autologous bone grafts are generally considered to have higher osteogenic potential compared to allografts. However, no comparison was made regarding the superiority between cortical bone graft [7,31], which offers structural stability

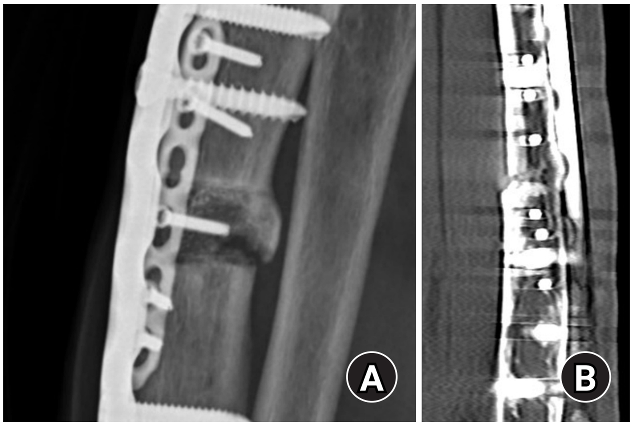

Fig. 7. At 20 weeks after the operation, the grafted bone was coaptated in the right arm (A) and united in the left arm (B).

advantages as in the right forearm, and cancellous bone graft [2], which offers advantages for osteogenesis as in the left forearm. Nonetheless, bone union was confirmed in both groups simultaneously.

The second consideration was fixation stability. We utilized a 3.5 mm LC-LCP straight plate in both forearms, applying a 10-hole plate in the right forearm and a 9-hole plate in the left. Additional 2.0 mm small fragment plates of 6 and 7 holes were added to the right and left forearms, respectively. Notably, the right small plate secured the grafted cortical bone. Although the optimal number of cortices and the length of the plate were not definitively determined, prior studies have suggested that greater stability is advisable compared to primary ulnar fractures. Some authors reported the usefulness of the dual plate for more rigid internal fixation [2,32].

Lastly, while not related to fracture healing, consideration must be given to the elbow and wrist joints in forearm fractures. Despite the absence of ulnar-sided wrist pain before or after the operation, ulnocarpal impaction was evident in the wrist radiogram, attributed to a lunate bone lesion. By reducing the resected bone margin in the left forearm, we could decrease the required amount of harvested cancellous bone graft while also unintentionally performing ulnar shortening osteotomy—a classic treatment for ulnocarpal impaction syndrome.

This study has several limitations. Despite our attempts to contact the patient by phone, we were unable to obtain long-term follow-up radiographs to provide further insight for the readership. Instead, Fig. 8 presents a lateral radiograph from a different 85-year-old female patient who underwent a similar procedure using an iliac cortico-cancellous structural bone graft. The radiograph, taken 20 months postoperatively, demonstrates a similarly favorable outcome.

Fig. 8. Lateral radiograph of a different 85-year-old female patient taken 20 months postoperatively. The patient was treated with an iliac cortico-cancellous structural bone graft and showed favorable outcomes. The grafted cortical bone was soundly coaptated (circle) to both the proximal and distal segments of the ulna, as demonstrated in the image.

Although osteosynthesis resulted in favorable clinical outcomes, it remains unclear which type of bone graft—cortical or cancellous—offers superior results, as well as optimizing fixation plate application for sufficient stability, remains uncertain. These limitations underscore the need for further clinical experience and research in the future.

In Table 2, we summarize the treatment guidelines for AUFs based on previously published literature and our own limited clinical experience.

Conclusions

AUFs represent a rare but clinically significant complication of long-term antiresorptive therapy. Given their distinct pathophysiology and mechanical environment

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Table 2. Summary of the guideline for atypical ulnar fracture treatment

Category	Key point
Preoperative evaluation	Review medical history for use of antiresorptive agents
	Conduct a laboratory evaluation of bone health profile
	Use radiologic studies (X-ray and bone scan) to detect other atypical lesions, including subtrochanteric areas
	Discontinue antiresorptive agents preoperatively
	Perform a DEXA scan to evaluate current bone density status
Operative principles	Focus on improving biological healing and fixation stability during osteosynthesis
	Debate remains regarding extent of debridement/resection and type of bone graft (cortical vs. cancellous)
	Decision algorithm for graft type: use cortical for large segmental defects with mechanical stability; cancellous for enhancing osteogenesis in smaller gaps
	Robust fixation recommended: long plate, dual plating, or combined plate and nail techniques
Postoperative management	Recommend PTH therapy; calcium and vitamin D supplementation (despite inconclusive evidence)
	Coordinate with medical team for follow-up medical management
	More protection using immobilization and a longer bone union period are required, making close outpatient follow-up imperative

DEXA, dual-energy X-ray absorptiometry; PTH, parathyroid hormone.

compared to typical ulnar fractures, successful management requires both biological and mechanical optimization. Surgical strategies emphasizing complete resection of unhealthy sclerotic margins, autologous bone grafting either cortical or cancellous depending on the defect characteristics and rigid plate fixation with long and double plating yielded favorable outcomes in our bilateral AUF case. Further accumulation of clinical cases and prospective research are necessary to refine diagnostic criteria and optimize therapeutic approaches for AUFs.

Article Information

Author contributions

Conceptualization: CHO, HTK, JKL. Data curation: CHO, HTK. Methodology: JKL. Investigation: CHO, HTK. Resources: HTK. Validation: HTK. Visualization: CHO, JKL. Writing-original draft: CHO. Writing-review & editing: HTK, JKL. All authors read and approved the final manuscript.

Conflicts of interest

Jun-Ku Lee is an editorial board member of the journal but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflicts of interest relevant to this article were reported.

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Data availability

Not applicable.

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Biomechanical finite element analysis of a femoral neck system fixation construct for femur neck fractures and clinical implications

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Background: This study assessed the structural/mechanical stability of fixation constructs with a femoral neck system (FNS) via finite element analysis after simulating femoral neck fractures and explored the clinical implications.
Methods: We simulated subcapital, transcervical, basicervical, and vertical fracture models using a right femur (SAWBONES) and imported the implant model of FNS to Ansys (Ansys 19.0, Ansys Inc.) to place the implant in the optimal position. The distal end of the femur model was completely fixed and was abducted 7°. The force vector was set laterally at an angle of 3° and posteriorly at an angle of 15° in the vertical ground. The analysis was conducted using Ansys software with the von Mises stress (VMS) in megapascals (MPa).
Results: The maximum VMS of the fracture site was 67.01 MPa for a subcapital, 68.56 MPa for a transcervical, 344.54 MPa for a basicervical, and 130.59 MPa for a vertical model. The maximum VMS of FNS was 840.34 MPa for a subcapital, 637.37 MPa for a transcervical, 464.07 MPa for a basicervical, and 421.01 MPa for a vertical model. The stress distribution of basicervical and vertical fractures differed significantly, and the basicervical fracture had higher VMS at the bone, implant, and fracture sites.
Conclusions: FNS fixation should be performed with consideration the osseous anchorage in the femoral head, and this technique might be appropriate for vertical fractures. Regarding the VMS at the fracture site, FNS might be applied cautiously only to basicervical fractures with anatomical reduction without a gap or comminution.
Level of evidence: IV.

Keywords: Proximal femoral fractures; Fracture fixation; Finite element analysis

Original Article

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Introduction

Considering that fracture site and orientation affect management modality and fixation construct in the treatment of young femoral neck fracture (FNF), trauma surgeons need convenient and reproducible standards to help them choose the best surgical implant and predict fracture-related complications [1,2]. Of FNFs in young adults, vertically oriented FNF (Pauwels type III) should be distinguished, because the high shearing force could explain the relatively high rate of nonunion and fixation failure [3-7]. It has been well established that anatomic reduction and choice of optimal implant are crucial for minimizing complications of FNF in young adults.

Although the reduction adequacy was dependent on the surgeon's experience and tactics, the implant choice is based on preoperative planning with an accurate assessment of fracture morphology, especially in high-energy injuries. These fractures are often stabilized with multiple cannulated screws (MCS), dynamic hip screws (DHS) with or without an anti-rotation screw [8-11].

Recently, the new minimally invasive implant femoral neck system (FNS; DePuySynthes) developed for dynamic fixation of FNFs. Owing to the advantages of angular stability with a minimally invasive surgical technique [12], the indications for FNS have been significantly broadened and have led to an increase in the use for various FNFs, although there is little evidence for clinical outcomes. Concerning the FNS implantation for highly unstable FNSs, there have been two main types of research: (1) retrospective analysis of clinical results and (2) biomechanical investigation enhancing the structural-mechanical stability [10,13-15]. However, few studies have measured biomechanical behavior according to the patterns of FNFs under the same conditions. Hence, by using the widely accepted finite element (FE) method [16-18], we would demonstrate the difference in structural-mechanical stability according to the patterns of FNFs and introduce the clinical implications of FNS.

Methods

Development of the FE Model

This study did not need approval by the Institutional Review Board, because its three-dimensional (3D) computer-aided design (CAD) model was from the commercially available high-resolution file of a right femur model: the standard fourth-generation composite bones (SAWBONES). Given the commercially available FNS, we modeled the 3D implant at actual size by using the 3D CAD software of SolidWorks 2019 (Dassault Systems SolidWorks Co.). Both the 3D femur and FNS were imported to SolidWorks for further polishing and were meshed using 1.0-mm tetrahedral mesh (Table 1).

The geometry of FE models corresponded to the definition of FNFs, including the subcapital, transcervical, basicervical [19], and vertical fractures [7]. The neck fractures were simulated in 3D CAD software of SolidWorks. Then, the 3D models of implant and femur were imported to the Ansys software (Ansys 19.0, Ansys Inc.) for placing the FNS in the optimal position and subsequently establishing the FE model by remeshing (Fig. 1). For FE analysis, the principles of model construction were uniform, as follows: (1) The plate with one hole made contact with the femoral diaphysis; (2) The trajectory of the screws was chosen based on the locking hole of the plate so that they protruded over 2 mm on the opposite side; (3) The contact between plate and screw was simulated as the bonding with virtual mechanical rigid links to mimic the locking head screw mechanism; (4) The bolt (screw) was inserted through the femoral head center or center-inferior at less than 10 mm in any direction from the outer boundary of the femoral head in concordance with the well-accepted technique of the manufacturer's instructions [20].

Material Properties, Boundary Conditions, and Stress Analysis of Fixation Constructs

The material properties for the synthetic femur were assigned according to the manufacturer's specification for the fourth-generation SAWBONES (Table 1). We set the Young's modulus of the cortical bone at 7,200 megapascal (MPa) with a Poisson's ratio (y) of 0.350 and set it for the cancellous bone at 135 MPa with Poisson ratio (y) of 0.225. The density of the cortical bone was 1.5 g/cm^3, and that of the cancellous bone was 0.2 g/cm [21,22]. All the metal of the implants was assumed to have the elastic, isotropic and homogeneous properties of titanium alloy in this study. The Young's modulus of the titanium alloy was set at 96,000 MPa with a Poisson's ratio (y) of 0.36 and the density of the implant was 4.62 g/cm [21].

Table 1. Material properties of bone and implant

Material	Density (g/cm^3)	Elastic modulus (megapascal)	Poisson's ratio
Cortical bone	1.5	7,200	0.35
Cancellous bone	0.2	135	0.225
Titanium alloy (fixation implant)	4.62	96,000	0.36

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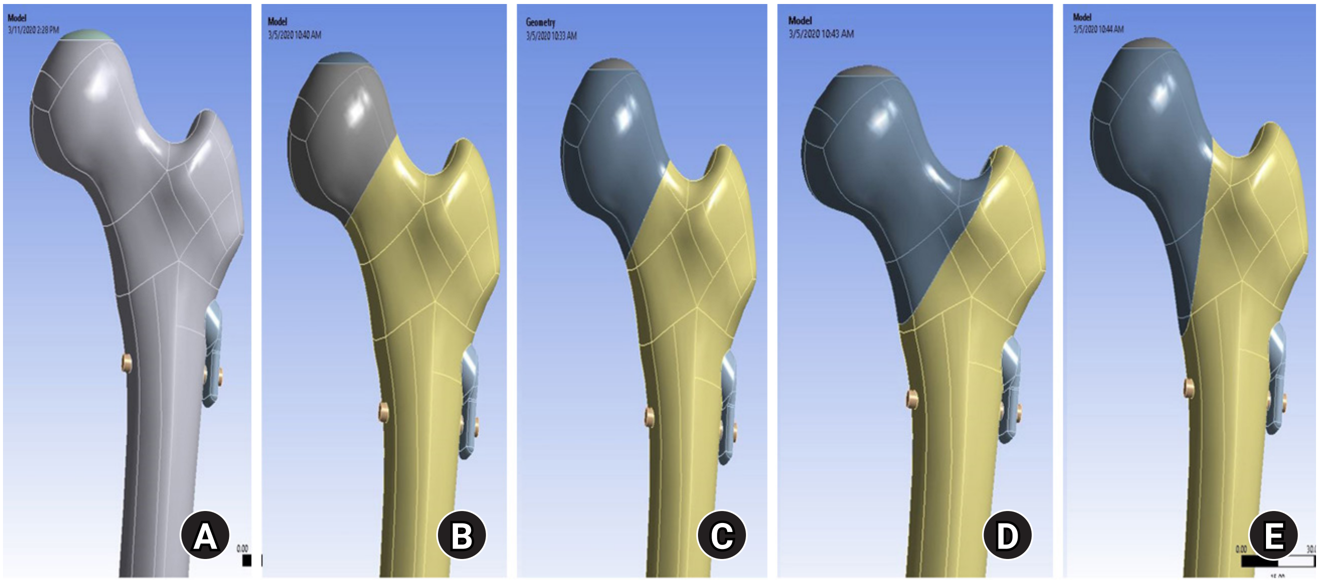

Fig. 1. The neck fractures were simulated in three-dimensional (3D) computer-aided design software (SolidWorks 2019, Dassault Systems SolidWorks Co.). Then, the 3D models of the implant and femur were imported to Ansys software (Ansys 19.0, Ansys Inc.) in order to place the femoral neck fracture in the optimal position. (A) No fracture. (B) Subcapital F. (C) Transcervical F. (D) Basicervical F. (E) Vertical F.

The distal end of the femur model was completely fixed, and the loads of 1950 N, equivalent to tripling the body weight of the subject (65 kg), were applied to the center of the femoral head [23]. To mimic the normally physiologic alignment of lower limbs in the standing position, each assembly model was abducted 7° in the vertical ground (Fig. 1). The force vector was set laterally at an angle of 3° and posteriorly at 15°, because the femoral neck was slightly anteverted in relation to the position of the femoral condyles in the horizontal or transverse plane [24]. The 3D shear stress on the X axis was 98.57 N, 1947.3 N on the Y axis, and 26.4 N on the Z axis. We assumed that the implant was in direct contact with the bone (Table 1). According to the well-established and approved test contact setup method described in previous studies, a binding contact was formed between the internal fixation screw and the femur [25]. We could not evaluate the torsional results in these models. We assumed that the implant had direct contact with the bone and did the analysis using commercial FE software of Ansys with von Mises stress (VMS) in MPa, fracture displacement of the implant relative to the bone (as a measure of relative fixation strength).

Results

According to the displacement of the assembly model, the maximum displacement occurs at the upper part of the femoral head, as shown in Fig. 2. The displacements of the proximal femur were 9.28 mm for the no-fracture model, 9.61 mm for the subcapital fracture, 9.77 mm for the transcervical fracture, 9.86 mm for the basicervical fracture, and 9.87 mm for the vertical fracture. The VMS distributions on bone were assessed and are shown in Fig. 3. Compared with the no-fracture model, the subcapital and transcervical fracture had a similar distribution of VMS, which was the medial exit point of the screw through the plate (Fig. 4). The vertical fracture was the lateral insertion point of the plate. However, for the basicervical fracture, the max point of VMS was different from that in the other models and was in the posteromedial side of the fracture site (Fig. 5).

The max VMS of the fracture site was 67.01 MPa for the subcapital fracture, 68.56 MPa for the transcervical fracture, 344.54 MPa for the basicervical fracture, and 130.59 MPa for the vertical fracture (Fig. 6). For the stress distribution on the FNS, there were some differences based on the fracture morphologies. The max VMS of the implant was 840.34 MPa for the subcapital fracture, 637.37 MPa for the transcervical fracture, 464.07 MPa for the basicervical

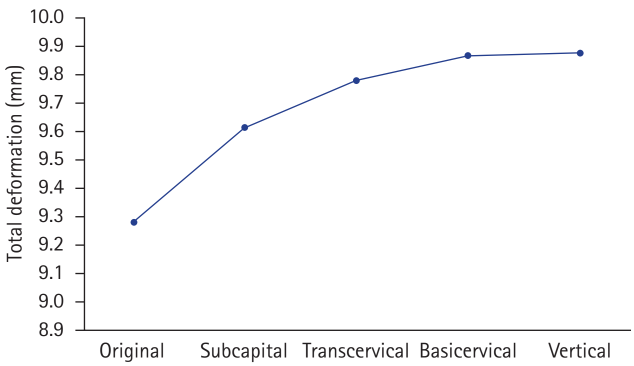

Fig. 2. According to the displacement of the assembly model, the maximum displacement occurs at the upper part of the femoral head. The displacement was the largest in basicervical and vertical fractures.

fracture, and 421.01 MPa for the vertical fracture (Fig. 6). For the stress distribution on the implant, the max points of VMS were the bolt around fracture site in all models and were in the junction site between the fracture site and the barrel of the plate (Fig. 7). There were two kinds of stress distribution of the bolt according to the fracture morphologies. The max point of the subcapital and transcervical fractures was the upper junction site, like that in the no-fracture model, and was the lower junction site for the basicervical and vertical fractures (Fig. 8).

Considering the max VMS distributions on the assembly models, the max VMS of the implant corresponded to the value of the entire fixation construct; so, the FNS mainly

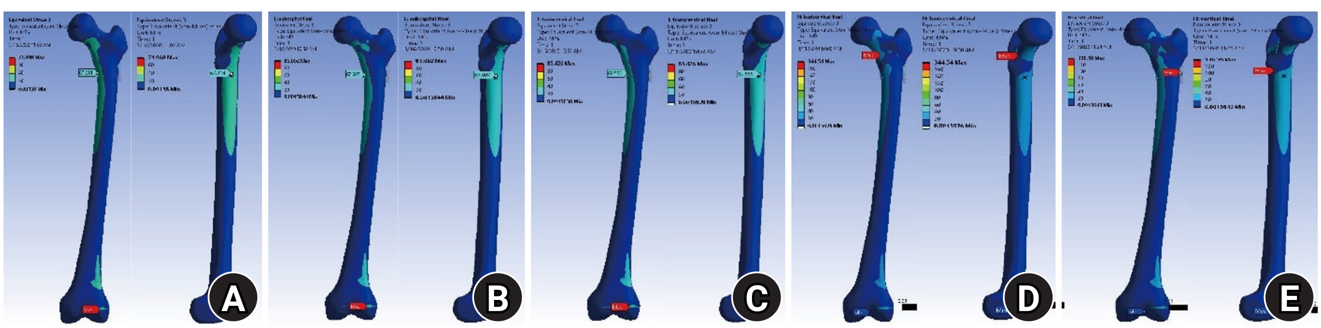

Fig. 3. The von Mises stress (VMS) distributions on bone. Compared with the no-fracture model, the subcapital and transcervical fractures had a similar VMS distribution, which was the medial exit point of the screw through the plate. However, for the basicervical and vertical fractures, the max point of VMS was different from that in other models and was located in the medial side of the fracture site. (A) No fracture. (B) Subcapital F. (C) Transcervical F. (D) Basicervical F. (E) Vertical F.

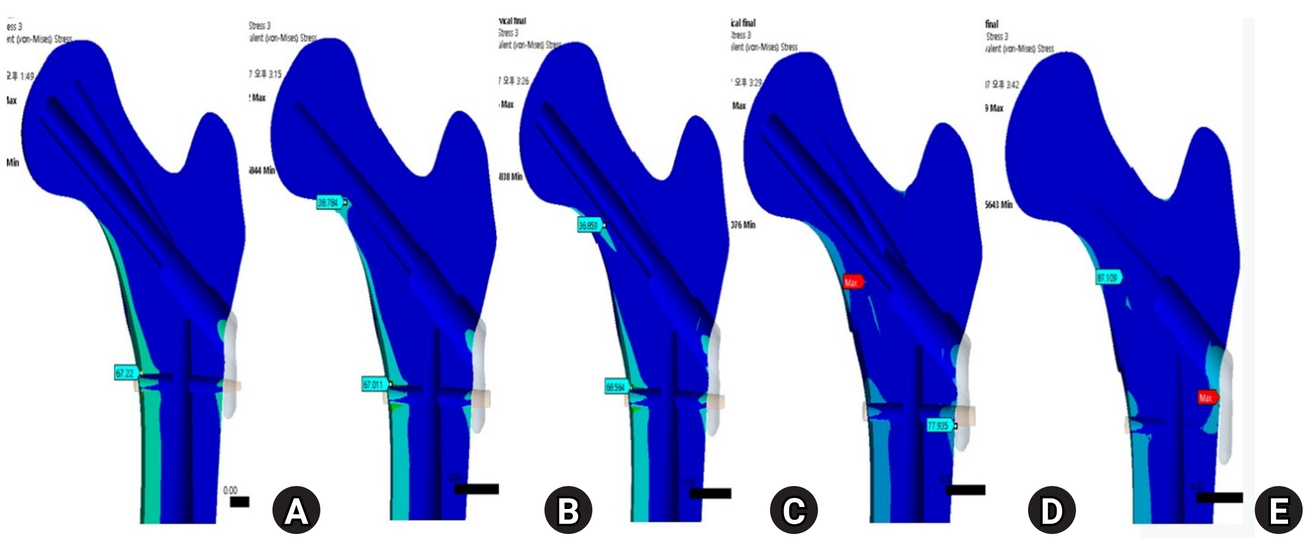

Fig. 4. Compared with the no-fracture model, the subcapital and transcervical fractures had a similar von Mises stress distribution, which was the medial exit point of the screw through the plate. (A) No fracture. (B) Subcapital F. (C) Transcervical F. (D) Basicervical F. (E) Vertical F.

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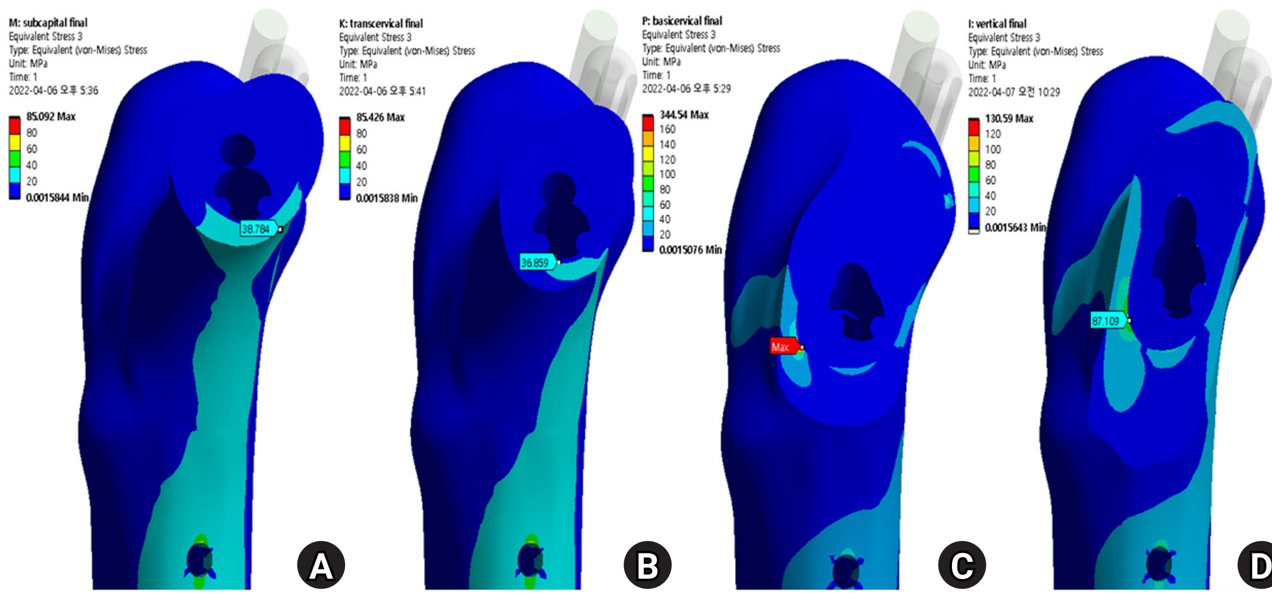

Fig. 5. The stress distribution of the fracture site was notably increased in the basicervical fracture, for which the point with the maximum von Mises stress was different from that in other models and was located in the posteroinferior area of the fracture site. (A) Subcapital F. (B) Transcervical F. (C) Basicervical F. (D) Vertical F.

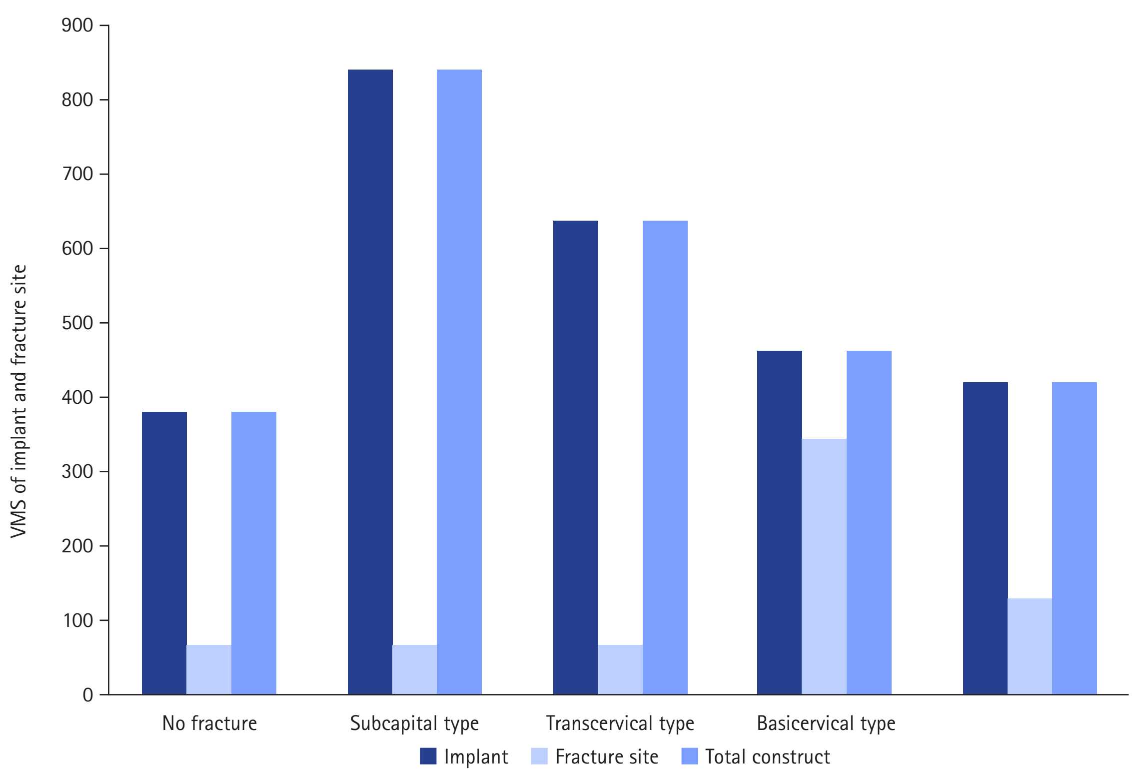

Fig. 6. von Mises stress (VMS) of implant and fracture site. The maximum VMS of the fracture site was 67.01 megapascal (MPa) for the subcapital fracture, 68.56 MPa for the transcervical fracture, 344.54 MPa for the basicervical fracture, and 130.59 MPa for the vertical fracture.

served for load-bearing, because the stress value of the fracture site was small except for the basicervical fracture. In terms of the load-bearing role, the implant's VMS was the highest in the subcapital fracture and lowest in the vertical fracture. For the basicervical and vertical fractures, the stress distribution between the implant and fracture sites differed significantly; the basicervical fracture had higher VMS in the bone, implant, and fracture sites (Fig. 9).

Discussion

Although controversy remains regarding optimal fixation

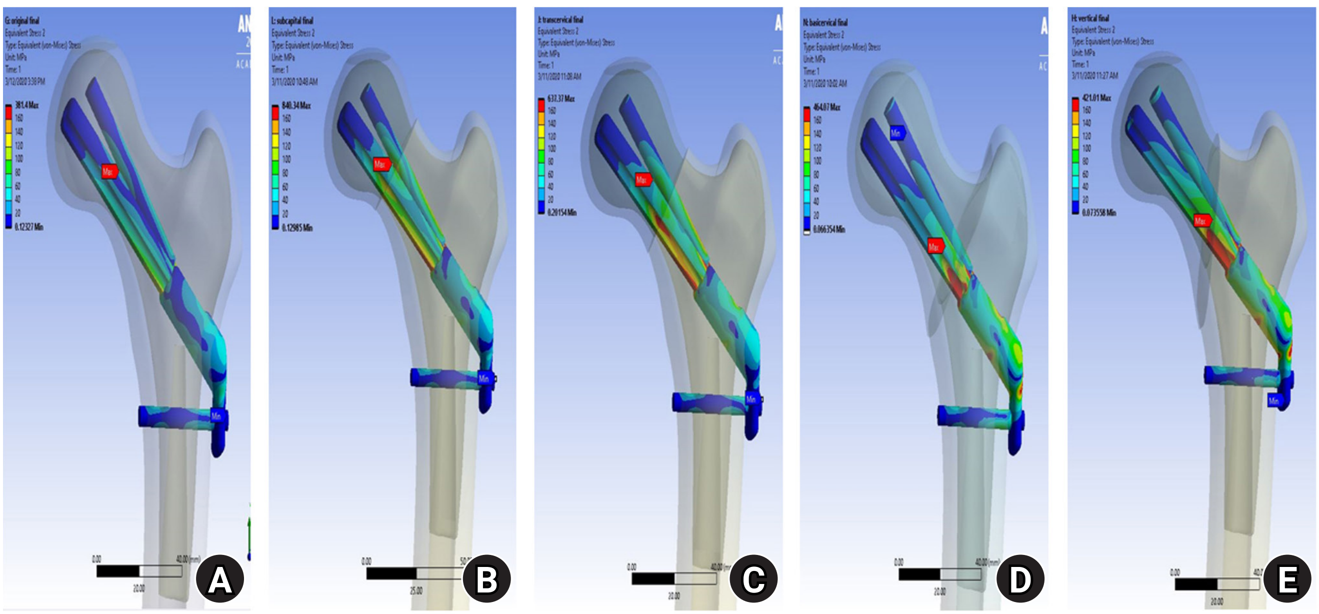

Fig. 7. For the stress distribution on the implant, the points with the maximum von Mises stress were the bolt around the fracture site in all models; it was located in the junction between the fracture site and the barrel of the plate. (A) No fracture. (B) Subcapital F. (C) Transcervical F. (D) Basicervical F. (E) Vertical F.

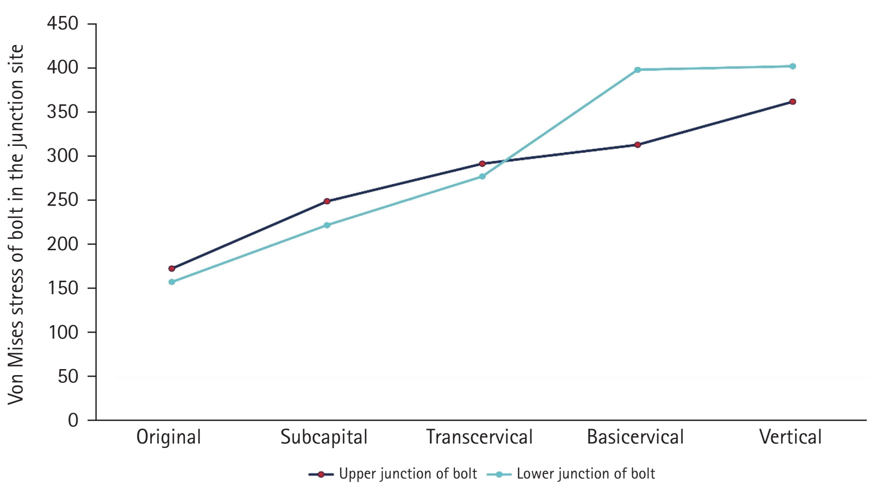

Fig. 8. von Mises stress of bolt in the junction site. There were two kinds of stress distribution of the bolt according to the fracture morphologies. The maximum point of the subcapital and transcervical fractures was the upper junction site, as in the no-fracture model, and was the lower junction site for the basicervical and vertical fractures.

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techniques and constructs, strategies for achieving optimal stability are crucial to minimizing the complications and sequelae in the management of high-energy FNFs. We conducted the FE analysis to assess the structural-mechanical stability of FNS in the nonosteoporotic FNFs. This computational analysis enabled us to arrive at several interesting findings. First, the max VMS of FNS corresponded to the value of the entire fixation construct and mainly functioned as the load-bearing implant. Second, for the subcapital and transcervical fractures, the stress distribution mainly concentrated on the implant and thus, the proximal osseous anchoring of the bolt might be necessary for maintaining rotational and angular stability. Third, the max VMS point of the fracture site was located on the posteroinferior side of the fracture site in the basicervical and vertical fractures. The VMS of the basicervical fracture was significantly larger than that of vertical fracture.

Although various implants exist for the operative fixation of FNFs, the use of FNS has been increased because of its biomechanical advantages with minimally invasiveness [12]. Thus, the surgical complications, including the cut-out, nonunion, and femoral head necrosis, inevitably have occurred [9,26]. To our best knowledge, there was no clinical report of FNS complications according to the fracture morphologies or Pauwels angle, although several studies have reported the comparative results of FNS and MCS [8-10]. Thus, considering these limitations of clinical case studies, we aimed to investigate the biomechanical behaviors of FNS based on the traditional classification of FNFs. Although it has been well established as most unstable fracture types, the VMS distribution of vertical fracture was similar to the no-fracture model but was much different from the basicervical fracture. The stress distribution of the fracture site was notably increased in the basicervical fracture. Thus, if the FNS fixation is considered for a basicervical fracture, the related factors of the variant types

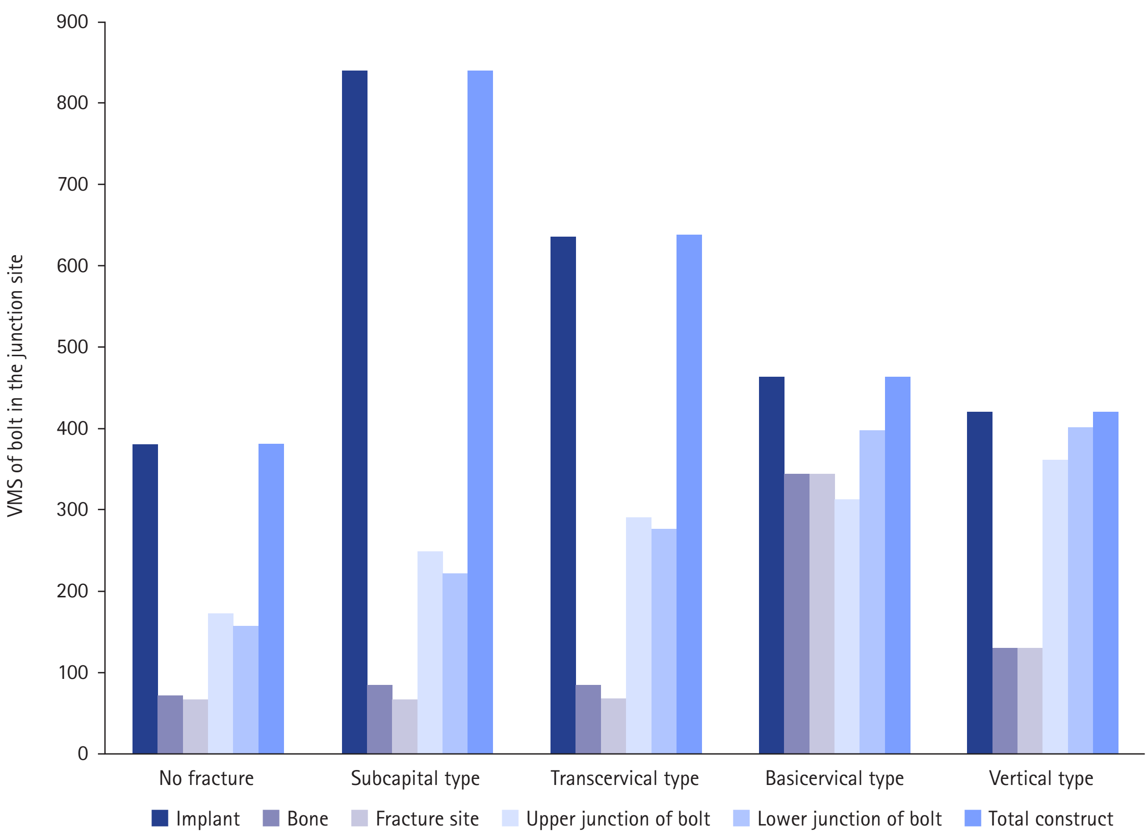

Fig. 9. von Mises stress (VMS) of bolt in the junction site in terms of the load-bearing role, the implant's VMS was the highest in the subcapital fracture and lowest in the vertical fracture. Comparing the basicervical and vertical fractures, the stress distribution between the implant and fracture sites differed significantly, and the basicervical fracture had higher VMS in the bone, implant, and fracture sites.

[27,28] and reduction adequacy, which are anatomically cortical contact, posteroinferior comminution, and fracture gap, should be verified intraoperatively before the definitive fixation. Because the vertically oriented fracture may contribute to the high failure rate in Pauwels' grade III fractures in healthy young patient, the DHS with or without a de-rotational screw has been regarded as a superior fixation construct [4,29]. Before this investigation to identify the optimal indications, we anticipated that FNS may not be appropriate for vertical fractures, because it is a smaller implant of plate and lag screw (bolt) than is DHS. Although we did not analyze the direct comparison between FNS and DHS, our results demonstrated that the stress distribution of the fixation construct was concentrated on the implant and not the fracture site.

When compared between vertical fracture and basicervical fracture, the max VMS value of the implant was not significantly different, but it was much different at the fracture site. Thus, despite these prejudices, we think the vertical fracture might be more suitable for FNS fixation than the basicervical fracture. Furthermore, considering that 96% of vertical neck fractures had major comminution, which was mainly located inferiorly and posteriorly [30], the FNS for vertical fractures might be an appropriate implant for vertical fracture based on our results, which showed the lower stress distribution on the fracture site. Additionally, compared with the no-fracture model, the VMS distribution of the vertical fracture was most similar in the fracture site and implant. For the subcapital fracture, the stress distribution mainly concentrated on the implant, and the max points of VMS were the bolt around the fracture site. Based on this result, authors should assume that the anchoring between the proximal bolt and the cancellous bone of the femoral head is maximized. In the personal communication between orthopedic trauma surgeons, we found that fixation failure of FNS was not uncommon, although the critical factors could not be analyzed. However, this FE analysis seems to show that the proximal osseous anchoring of the bolt might be essential for maintaining rotational and angular stability. The subcapital fracture might be cautiously applied because the femoral head fragment had a short working length. Adding an anti-rotational screw to the FNS might increase the proximal anchoring and angular stability, so further research on this topic will be performed in the future (Fig. 10).

Despite interesting findings, this computational simulation study has several fundamental limitations. First, our fracture models were very simplified for simulating the perfect reduction without gap and comminution between fragments. Second, our results had descriptive characteristics because we used not patient-specific computed tomography-based bone models but synthetic bone models, which were simulated using a normal nonosteoporotic femur without considering the heterogeneous properties of real human bone. Third, the fracture impact by controlled sliding of the lag screw/blade could not be simulated, because of technical difficulties. Our results just showed the initial strength of the fixation construct. Nevertheless, our computational analysis could be assessed on structural-mechanical strength and the VMS distribution of the fracture site and the implant under the same conditions. Although the implant should be chosen in terms of the extent of displacement, fracture configuration, physiological age, bone quality, and other factors, our results might be able to directly suggest technical relevance to maximize the structural strength of the FNS fixation construct for FNFs. By utilizing previous research experience, we will conduct a comparative study of other fixation constructs, including the DHS, MCS, and intramedullary nails, in the future. Additionally, further research is needed to determine what makes the difference between basicervical fracture and vertical fracture fixed with FNS.

Conclusions

Based on the stress distribution of fracture sites and implants, the FNS fixation construct might be appropriate for transcervical and vertical fractures. For a basicervical fracture, an FNS might be applied in the anatomically reduced fracture without gap and comminution. For subcapital fractures, considering the high-stress distribution of the proximal bolt around fracture site, there are two important things; (1) The osseous anchorage of femoral head might be essential to maintain the structure-mechanical stability. (2) The working length of the bolt in the femoral head is verified preoperatively.

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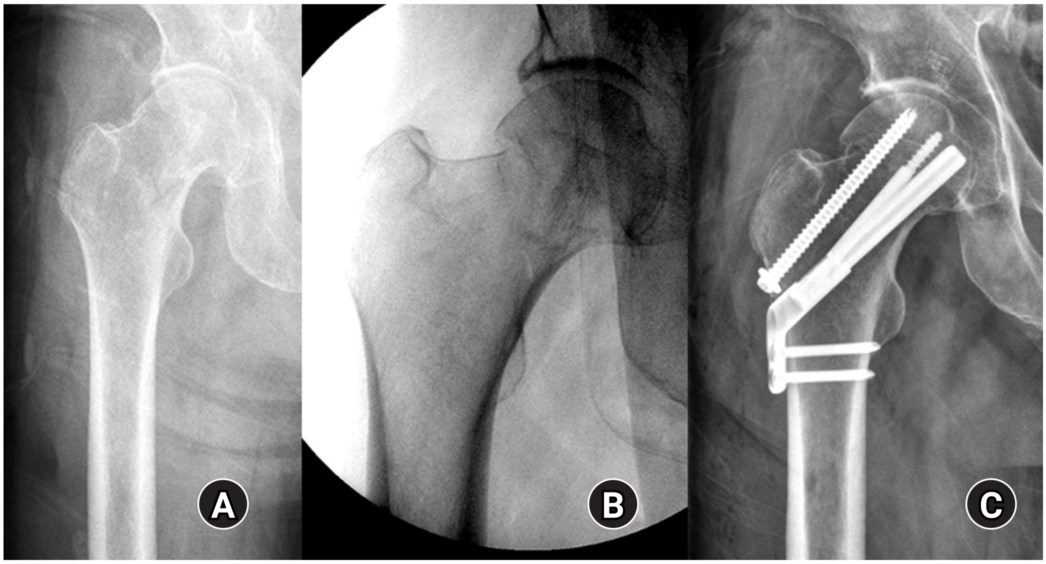

Fig. 10. A 54-year-old male patient sustained a femoral neck fracture caused by a fall from a 2-m height. (A, B) Plain radiographs and an intraoperative fluoroscopic image show the subcapital fracture. (C) The femoral neck system anti-rotational screw was applied to increase the anchoring and stability of the femoral head fragment.

Article Information

Author contributions

Data curation: SLJ. Formal analysis: HSS. Methodology: HSS, SLJ. Funding acquisition: GHJ. Supervision: GHJ. Visualization: SLJ. Writing-original draft: HSS, GHJ. Writing-review & editing: GHJ. All authors read and approved the final manuscript.

Conflicts of interest

Gu-Hee Jung is an editorial board member of the journal but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflicts of interest relevant to this article were reported.

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Data availability

Contact the corresponding author for data availability.

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Computational simulation of coracoclavicular screw insertion through the superior distal clavicular plate for clinical applications in Korean cadavers

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Background: The study was conducted to determine the practical area for inserting the coracoclavicular (CC) screw through the plate by analyzing three-dimensional (3D) shoulder models featuring virtually implanted, actual-size plates and screws.
Methods: Ninety cadaveric shoulders (41 males and 49 females) underwent continuous 1.0-mm slice computed tomography scans. The data were imported into image-processing software to generate a 3D shoulder model, including the scapula and clavicle. The overlapping area between the clavicle and the horizontal portion of the coracoid process (horizontal portion$_{_CP}$) was analyzed in the cranial view. A curved pelvic recon plate was virtually placed on the upper surface of the distal clavicle, and an actual-size (3.5 mm) CC screw was inserted through the plate.
Results: The distal clavicle directly overlapped with the horizontal portion$_{_CP}$ in the vertical direction. The overlapping area was sufficient to place the 3.5 mm and 4.5 mm-sized screws. In all shoulder models, the CC screw could be inserted through the plate into the vertical direction, with an average length of 35.5 mm (range, 26.2–62.5 mm; standard deviation, 1.2 mm). In 87 models, the CC screw was inserted through the third hole from the lateral end of the plate. Two models were inserted through the second hole, and one model through the fourth hole.
Conclusions: The upper surface of the clavicle has sufficient overlapping area to place CC screws through the plate in the vertical direction in the corresponding hole. Supplemental CC screw fixation through the plate can be performed without additional or special equipment.
Level of evidence: IV

Keywords: Clavicle; Bone fractures; Coracoclavicular joint; Bone screw; Computer simulation

Introduction

Surgical treatment of distal clavicular fractures can be challenging because of the deforming forces on the proximal clavicle and characteristically small distal fragments that limit quality fixation. Numerous surgical options have been reported. These have yielded varying results, with diverse rates of associated complications and reoperation [1]. No consensus has been reached on the optimal treatment, especially in Neer type IIB fractures. In managing an unstable distal clavicular fracture, if fixation of the distal fragment is judged to be inadequate, fixation may need to be augmented using a hook plate with fixation under the acromion or supplemental coracoclavicular (CC) fixation combined with the superior distal clavicular plate fixation to prevent superior migration of the proximal fragment [2-4].

Considering the complications related with hook plate fixation for the distal clavicular fractures [5-7], although contentious, supplemental CC fixation combined with the superior plating has more advantages and has been performed using various options when there is insufficient bony purchase in the distal fragment with multiple screws [8-12]. Among the various options, supplemental CC screw fixation through the plate could be performed into the coracoid process without additional implant and instruments whenever needed. However, practically, most surgeons have been concerned with the proper and safe screw trajectory into the coracoid process due to the complicated three-dimensional (3D) anatomy. Although the horizontal portion of coracoid process (horizontal portion$_{\text{_CP}}$) has long been used as the osseous site to achieve the fixation constructs including the CC ligament reconstruction, Bosworth screw fixation, and others, there was no detailed information on safe zone and ideal entry point for screw fixation on the upper surface of clavicle. Therefore, the primary purpose of this computational study was to verify the practical area for inserting the CC screw through the plate and introduce the landmark for clinical application by analyzing the 3D shoulder models featuring virtually implanted, actual size plate and screws.

Methods

3D Reconstruction of Cadaveric Specimens

Digital images of the Korean human body were collected from the Korean Institute of Science and Technology Information and used by agreement. Adult cadavers (n=105) who underwent continuous 1.0 mm slice computed tomography (CT) scans (Pronto) in the supine position were included. None of the cadavers had scapular and clavicular problems based on the analysis of medical records. CT data in Digital Imaging and Communications in Medicine format were imported into Mimics software (Materialise Interactive Medical Image Control System, Materialise) to reconstruct the 3D shoulder models including the scapula and clavicle.

Computational Measurement Methods

After obtaining a 3D shoulder model, the straight distance on the upper surface of clavicle was measured using the distant measuring tool of the Mimics software. The distance averaged 141.6 mm (range, 120.7–163.5 mm; standard deviation [SD], 11.2) (Fig. 1). The transparency mode was

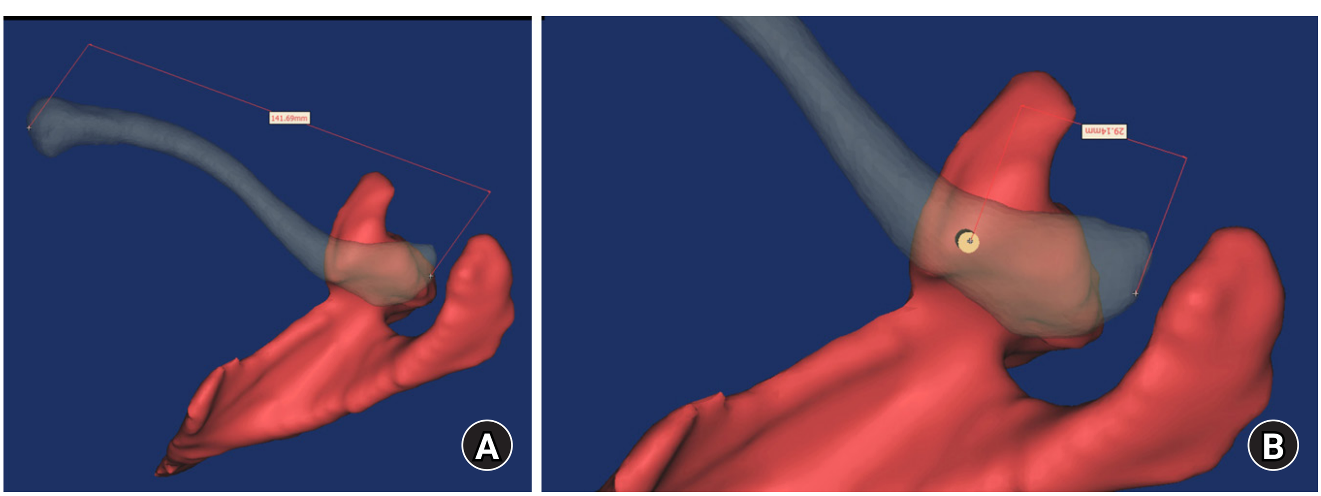

Fig. 1. Mimics software was used to reconstruct 3-dimentional models of the scapula and clavicle, and the transparency mode was controlled to identify the overlapping area between the clavicle and the coracoid process. The straight distance of the clavicle (A) and the distance between the lateral end of the clavicle and the elevated edge of the coracoid process (B) were measured using software.

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controlled to differentiate the overlapping area between the upper clavicular surface and the horizontal portion_$_{CP}$ in the cranial view. The straight distance on clavicle between the elevated ridge of horizontal portion_$_{CP}$ and lateral end of clavicle was measured on the upper surface of clavicle and defined as distance_$_{CP}$ (Fig. 1). For the computer-assisted simulation of CC screw fixation through the plate, a virtual 3D model of curved pelvic recon plate (Depuy-Synthes, GmbH) and 3.5 mm cortical screw were created using a 3D sensor (Comet5, Carl Zeiss) in actual size, and placed on the upper surface of distal clavicle using Mimics as with the distal clavicular superior plate fixation (Fig. 2). The ideal position of curved pelvic recon plate (plate) was defined as when the lateral end of plate corresponded to the lateral end of clavicle, the plate was centrally placed on the upper surface of clavicle in the cranial view, and the plate fit well in the anteroposterior (AP) view of the shoulder. After the definitive position of plate was fine-tuned and verified by an experienced surgeon (GHJ), the mutual location of plate holes, horizontal portion_$_{CP}$ and its elevated ridge, and medial border of coracoid process was assessed by controlling the rotation of shoulder model in the cranial and caudal views of the shoulder model. Virtual CC screw fixation through the plate with purchase of the horizontal portion_$_{CP}$ was performed using the Mimics software with a 3.5 mm cortical screw. The corresponding hole and relationship with the adjacent structure were identified.

Statistical Analysis

IBM SPSS ver. 23.0 (IBM Corp.) was used and statistical significance was set at P<0.05. The univariate and multivariate analyses were performed using logistic regression and linear regression models.

Results

Morphological Analysis of 3D Shoulder

Fifteen cadavers were not enrolled due to poor image quality. The 90 enrolled adult cadavers (41 males and 49 females) had a mean age of 52.9 years (range, 22–60 years; SD, 2.8) and a mean height of 160.5 cm (range, 146–176 cm; SD, 7.8). On the cranial view of the clavicle, the upper surface of the distal clavicle overlapped with the horizontal portion_$_{CP}$ in a crossed direction. The overlapping area was sufficient to place the 3.5 mm and 4.5 mm screws in all models (Fig. 3). After magnifying and freely rotating the 3D model, the elevated ridge was easily identified just medial

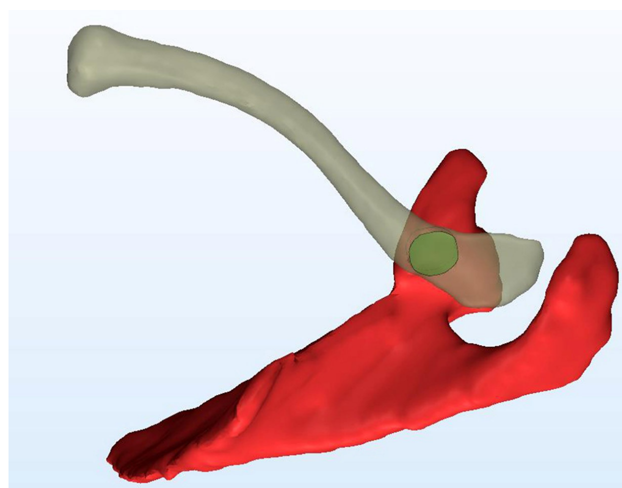

Fig. 3. On the cranial view of the clavicle, the upper surface of distal clavicle overlapped with the horizontal portion_coracoid process in a crossed direction. The overlapping area was located around the elevated edge and was sufficient to place the 3.5-mm and 4.5-mm screws.

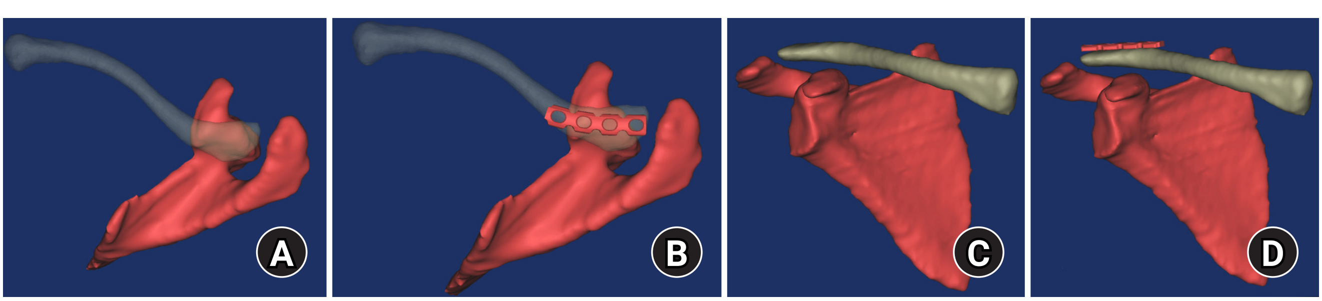

Fig. 2. The optimally positioned pelvic recon curved plate was defined as the central area being on the upper surface of the clavicle in the cranial view (A, B) and well fitted in the anteroposterior view (C, D).

to the ascending portion and was roughly placed in the central area of upper surface of clavicle. Distance$_{_CP}$ averaged 30.6 mm (range, 23.0–42.0 mm; SD, 1.1) and was statistically significant just with the clavicular length (P<0.001).

3D Analysis of Virtually Fixed Shoulder

Compared with the virtually placed plate in the ideal position, on the cranial view, the elevated ridge of 51 models was centrically matched with a central point of plate hole (third hole in 48 models, second hole in two models, and fourth hole in one model) and 39 models, eccentrically with the third hole (Table 1). On an AP view of the shoulder, the intersection point between the imaginary vertical line from the medial border of coracoid process and distal clavicle was always placed in the medial to the third hole of plate regardless of the degree of horizontal rotation of scapula (Fig. 4). On the lower surface of clavicle, the conoid tubercle was in accord with the possibility of three screws fixation in all models (Fig. 5). The findings clearly demonstrated that the distal clavicular fragment, which corresponded to the medial border of coracoid process and conoid process, had fixability of at least three screws through the plate.

In all shoulder models, the CC screw could be inserted through the plate into the horizontal portion$_{_CP}$ just in the vertical direction. The average length was an average 35.5 mm (range, 26.2–62.5 mm; SD, 2). The CC screw of 87 models was inserted through the third hole from the lateral end of the plate. Two models were through the second hole and through the fourth hole in one model (Fig. 6). Among

Table 1. Differences in distance$_{_CP}$

Group	No.	Mean	SD	95% CI	Minimum	Maximum
Second hole	2	23.1	0.07	22.41–23.69	23.0	23.1
Third hole	77	30.0	2.17	29.49–30.48	25.0	35.1
Fourth hole	11	36.7	3.04	34.67–38.75	35.2	42.0
Total	90	30.7	3.36	29.95–31.36	23.0	42.0

All measurements were expressed as millimeters (mm).
CP, horizontal portion; SD, standard deviation; CI, confidence interval.

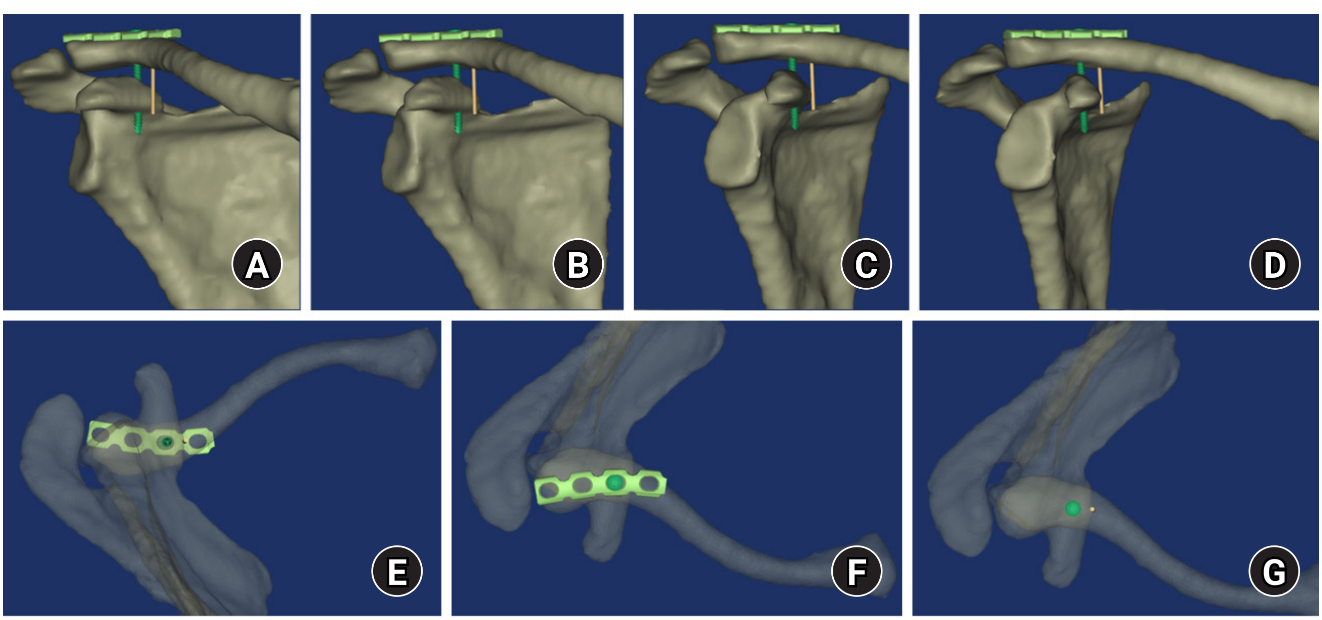

Fig. 4. On an anteroposterior view of the shoulder, the intersection point between the imaginary vertical line from the medial border of coracoid process and distal clavicle was always placed medial to the third hole of the plate regardless of the degree of horizontal rotation of the scapula (A–D). In the cranial view, the imaginary vertical line corresponded to the medial border of the overlapping area (E–G).

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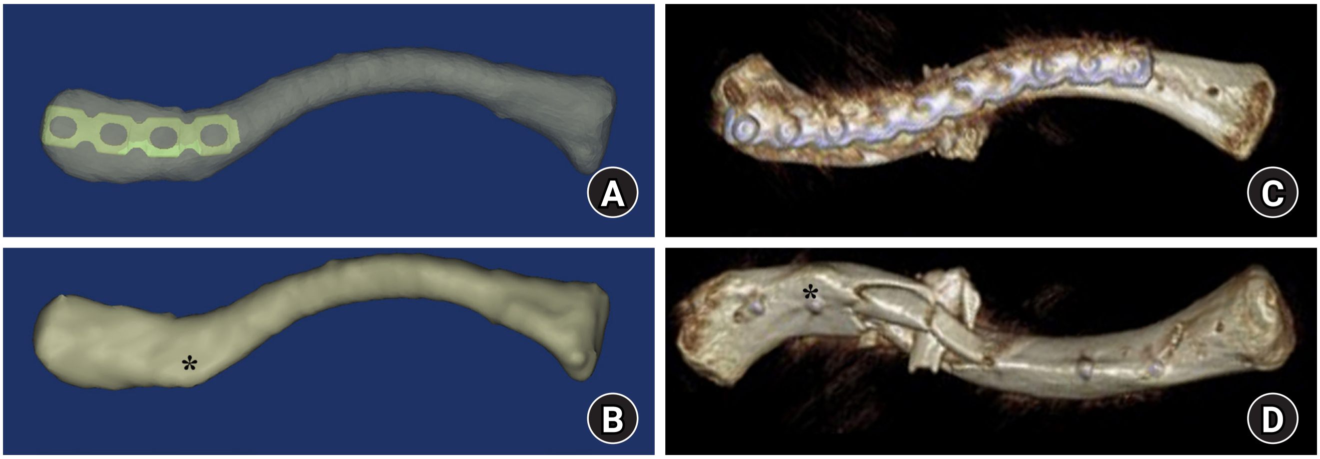

Fig. 5. On a caudal view of the clavicle, the conoid tubercle (asterisk) of the lower surface of the clavicle was in accordance with the possibility of three-screw fixation in all models (A, B). In the comminuted clavicular fracture, which was fixed with a pelvic curved recon plate through the bridge plating technique, a postoperative biplanar 3-dimentional image shows that the lateral fragment lateral to the conoid tubercle (asterisk) could be fixed with three screws (C, D).

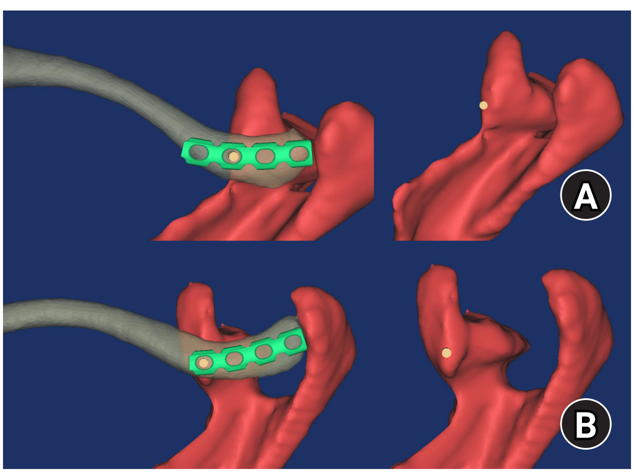

Fig. 6. Supplemental coracoclavicular screw fixation through the plate was inserted from the second hole in two models (A) and through the fourth hole in one model (B).

87 models, ten had sufficient overlapping area to place the two vertical and parallel CC screws through the third and fourth holes, which were assigned as the two screws model.

Statistical Correlation

Ten models with two vertical CC screws were exclusively males and displayed statistically significant clavicular length (P<0.001) and distance$_{\text{–CP}}$ (P<0.001). Based on the independent-sample T-test, the two groups were statistically different (P<0.001) (Table 2). When the Hosmer-Lemeshow test for goodness of fit was performed with the possibility of two CC screw fixation through the plate, the value of χ^2 was 2.291 (P=0.971). So, the logistic regression model was statistically significant. Among the anatomic variables, the sex (P=0.001), clavicular length (P<0.001), and distance$_{\text{–CP}}$ (P<0.001) were statistically significant. By multiple logistic regression model analysis, distance$_{\text{–CP}}$ was the only variable with a statistical significance (P<0.001). Receiver operating characteristic curve analysis using the distance$_{\text{–CP}}$ revealed an area under the curve of 0.976 (95% confidence interval [CI], 0.946–1.00), which indicated the suitability of distance$_{\text{–CP}}$ to predict the possibility of two CC screw placement through plate. The cut-off value of distance$_{\text{–CP}}$ was 33.6 mm (sensitivity, 0.90; specificity, 0.91). If distance$_{\text{–CP}}$ exceeded 33.6 mm, the distal clavicle would likely have sufficient osseous site on the upper clavicular surface for placing the two CC screws inside the horizontal portion$_{\text{–CP}}$.

Table 2. Comparison of two groups

Group	Mean	Standard deviation	T	P-value
Two CCS group	29.96	2.74	6.812	0.000
One CCS group	36.20	2.67		

CCS, coracoclavicular screw.

Discussion

For unstable distal clavicular fractures, the horizontal portion$_{_CP}$ has been used for the osseous site to achieve supplemental fixation constructs including the CC ligament surgeries, CC screw fixation, suture anchor insertion, and others [8-12]. However, these techniques need an additional procedure and implantation techniques for coracoid fixation, and are expensive. If the supplemental fixation is performed just by placing a screw through the plate on the upper surface of the clavicle, this fixation construct might be so convenient and useful in some injuries including poor bone quality and distal clavicular fractures with unexpected comminution [13,14]. Presently, we introduce the practical landmark and safe area for placing the CC screw through the plate and have identified the information for clinical application by virtually placing actual size plate and screws. This 3D anatomy study has a descriptive character, since the non-fractured clavicle of cadavers was analyzed. However, we anticipate that the results have practical value for several reasons: First, to the best of our knowledge, this is the only computational simulation study that has used actual size (3.5 mm) CC screw and plate. Second, the use of Mimics 3D rendering software to allow free 360° rotation with magnification in any plane allowed verification of the overlapping area (safe zone) and direct comparison with the plate holes. Third, it was clearly demonstrated that the CC screw through the plate could be inserted just by vertical direction in all models without additional procedure and special equipment.

Owing to the complications related with hook plate fixation for the distal clavicular fractures [5-7], the precontoured superior locking plating has been performed and good outcomes have been reported [4,15]. But, in practice, some distal clavicular fracture showed the unexpected comminuted fragments when using the open method, and is difficult to achieve sufficient bony purchase [16]. In these circumstances, despite some controversy, supplemental CC fixation combined with plate fixation has been viewed as the most preferred of the various options [17-19]. Unlike other techniques, the supplemental CC screw fixation through the plate can theoretically be performed without additional devices, implants, and instruments, and can be done as the occasion requires. However, we are not aware of anatomical information concerning the ideal entry point and safe zone. Although Andersen et al. [4] reported the advantages on the CC screw through the plate for distal clavicular fracture, they did not describe the technical reference. Tiefenboeck et al. [14] claimed that the clavicle was drilled by aiming the guide wire centrally towards the base of the coracoid process after manually identifying the coracoid tip. However, our computational simulation clearly found that the direct palpation of coracoid process was not required in this supplemental CC screw fixation technique. Once the clavicle was drilled through the hole of ideally-placed plate and aimed vertically, the CC screw of all models could purchase the osseous site around the elevated ridge of the horizontal portion$_{_CP}$ without an additional step. Even 10 models of male cadavers had sufficient overlapping area to place the two vertical and parallel CC screws through the third and fourth plate holes. Thus, in the unplanned and extemporary circumstance in which the lateral fragment was unexpectedly comminuted and even osteopenia in elderly patients and so did not seem to achieve the sufficient bony purchase, supplemental CC screw fixation through the plate could be undertaken. As well, since the simulated CC screw purchased the osseous site around the elevated ridge in which the trapezoid ligament was attached, anatomic reduction of the CC space might be achieved.

Considering that supplemental CC screw fixation through the plate is usually performed with fluoroscopic guidance, the intraoperative landmark or guideline might be important to verify the safe screw trajectory and prevent the neurovascular complications in practice. Since the scapula is not oriented in a true coronal plane, but lies in a coronal oblique plane, radiographic imaging of the entire coracoid process is difficult [20,21]. Although several radiographic views have been described, none can visualize each coracoid process in its entirety [21]. By our analysis of overlapping area on the cranial view, the practical landmark for CC screw insertion to place the plate centrally on the upper surface of clavicle was identified. AP view of the shoulder revealed the lack of necessity to aim the drill bit towards the base of the coracoid process to achieve the osseous purchase of the elevated ridge, since the CC screw could be inserted through the plate into the horizontal portion$_{_CP}$ in the vertical direction. Once the drill bit was placed just lateral to the ascending portion of coracoid process, there was an obvious screw purchase to the hori-

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zontal portion$_{\text{CP}}$ in the AP view, regardless of the patient's position and radiographic projection. Therefore, the imaginary vertical line from the medial border of the coracoid process could be used as the intraoperative guideline without special equipment. If the fracture line is medial to the intersection point between the clavicle and the imaginary vertical line during the fluoroscopic surgery, it would mean the lateral fragment had a fixability of at least three screws. Therefore, the imaginary vertical line might be useful for preoperative planning and the intraoperative procedure. Presently, the CC screw of 87 models (97%) was inserted through the third hole from the lateral end of the plate, which was easily identified by comparison between the plate and the imaginary vertical line. Henceforth, the corresponding hole for CC screw could be verified just by intraoperative fluoroscopic view (Fig. 4). These informative landmarks could be utilized to classify the fracture and choose the implant based on the fixability of distal clavicular fragments (Fig. 7).

Through this study, we found theoretically that 10 models (11%) had sufficient overlapping area to place the two vertical and parallel CC screws through the third and fourth plate holes. If the distance$_{\text{CP}}$ exceeded 33.6 mm, the overlapping area would likely be sufficient osseous site for placement of two CC screws. However, although the distance$_{\text{CP}}$ variable was utilized as preoperative radiologic marker, it could not be identified in the conventional CT scans. Thus, preferentially, the relationship between distance$_{\text{CP}}$ and the imaginary vertical line had to be verified in the AP view of the shoulder. By free 360° rotations with magnification in any plan of 3D shoulder model, the elevated ridge was easily recognizable as the convex surface just after the ascending portion. Considering that the lateral end of the distal clavicle and elevated ridge of the horizontal portion$_{\text{CP}}$ were conveniently localized during the operation, distance$_{\text{CP}}$ might be of practical value in predicting the possibility of two vertical CC screws and locating the corresponding hole for the supplemental CC screw in the various kinds of precontoured distal clavicular plate (Fig. 8).

This computational simulation study has several fundamental limitations. First, the indication of CC screw fixation through the plate was not clear, because the biomechanical and clinical advantages on CC screw fixation has not been proven. Second, considering the variables were manually measured, interobserver errors could occur. Third, owing to the small number of enrolled clavicles, our results cannot be generalized to all Asian people. Nevertheless, the findings indicate that supplemental CC screw fixation through the plate is an entirely safe and practically easy way to be placed without additional procedure and special equipment. Further studies on the clinical outcomes of supplemental CC screw through the plate and comparative study with other implant to augment fixation in distal clavicular fracture should be conducted in future.

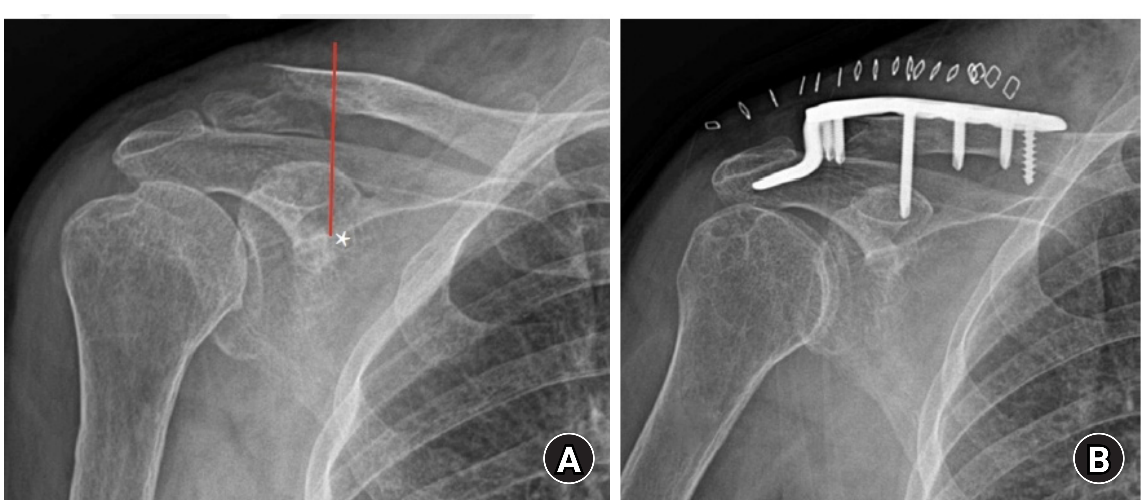

Fig. 7. An imaginary vertical line (asterisk) of preoperative radiograph could be utilized to classify the fracture and choose the implant based on the fixability of distal clavicular fragments (A, B).

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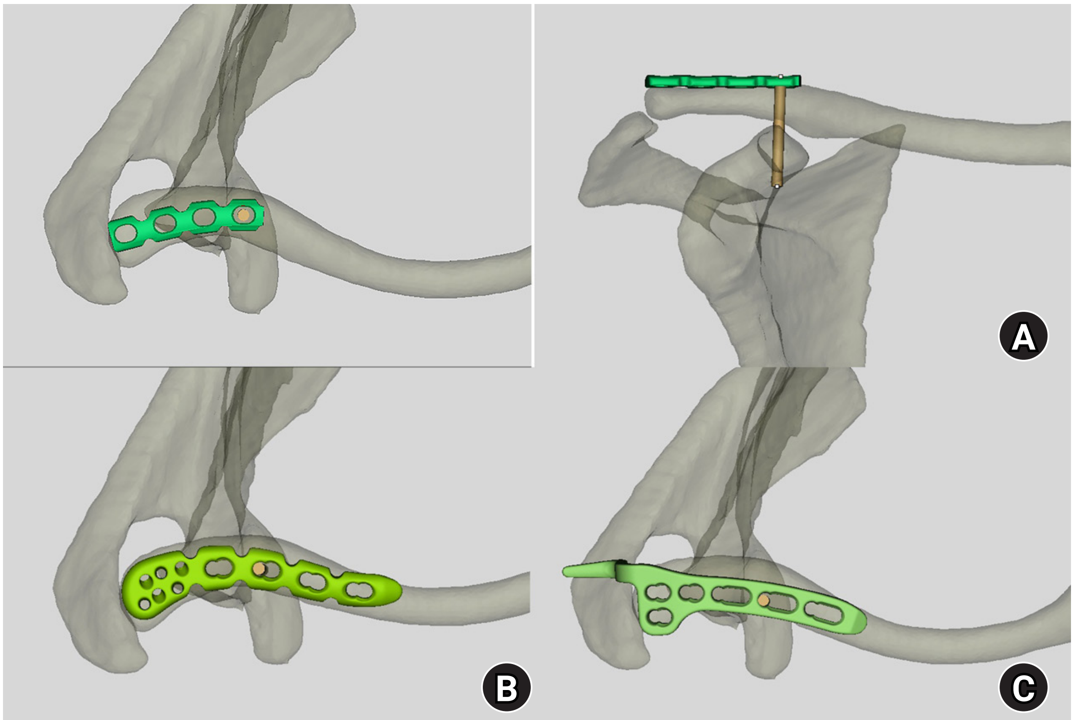

Fig. 8. Considering the convex surface of horizontal portion_coracoid process and imaginary vertical line, the corresponding hole for the supplemental coracoclavicular screw through the plate could be fixed in the various kinds of precontoured distal clavicular plate: (A) pelvic curved recon plate, (B) precontoured distal clavicular plate, and (C) distal clavicular hook plate.

Conclusions

This is the only study verifying the safe zone/trajectory, intraoperative landmark of vertical line, fixability of three screws on the distal clavicular fragment by simulating the supplemental CC screw through the plate in actual size. Considering the topographic features of overlapping area between the clavicle and horizonal portion, supplemental CC screw insertion through the plate could be placed safely over the horizontal portion$_{_CP}$ in the vertical direction in the corresponding hole without additional preparation, whenever the occasion requires.

Article Information

Author contributions

Data curation: JHC, SLJ. Formal analysis: HLC. Methodology: HLC. Visualization: SLJ, GHJ. Writing-original draft: SLJ, GHJ. Writing-review & editing: HLC, JHC, GHJ. All authors read and approved the final manuscript

Conflicts of interest

Gu-Hee Jung is an editorial board member of the journal but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflicts of interest relevant to this article were reported.

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Data availability

Contact the corresponding author for data availability.

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Lateral marginal fractures of the patella and patellofemoral pain

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Background: This study investigated the characteristics of lateral marginal fractures of the patella and evaluated the clinical outcomes.

Methods: We retrospectively reviewed all patients with lateral marginal fractures of the patella, defined as a vertical fracture line within 15 mm of the lateral patellar border, from 2008 to 2020. In total, 41 patients were included. Patient characteristics, radiologic findings, and clinical outcomes, including the Lysholm score at 1 year postoperation, were evaluated.

Results: The injury mechanisms were direct in 34 cases and indirect in seven. Furthermore, 85% of patients had a skyline view of the patella at the initial visit, and one medial subluxation of the patella was found. Forty of the 41 patients underwent surgery. Anatomical and nonanatomical (>1-mm displacement or excision) reductions were carried out in 36 cases (88%) and 5 cases (12%), respectively. The average Lysholm score was 89.1 (range, 67–99). The nonanatomical reduction group had a poorer functional score (79.8 vs. 90.4; P=0.010). Lateral patellar compression syndrome occurred in two patients with nonanatomical reduction.

Conclusions: Lateral marginal fractures of the patella affected patellofemoral stability. Anatomical reduction showed good functional outcomes, while nonanatomical reduction was associated with patellofemoral stability and pain. Therefore, surgeons should perform anatomical reduction with any appropriate fixation method.

Level of evidence: IV.

Keywords: Patella; Patellofemoral joint; Marginal fracture; Lateral marginal; Complications

Original Article

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Introduction

Patellar fractures account for approximately 1% of all fractures and may result from direct or indirect injury mechanisms [1]. The indirect mechanism consists of direct blow to anterior knee from a fall or dashboard injury. Indirect forces with eccentric contraction of the quadriceps typically lead to transverse fractures [2]. In contrast, a direct blow more likely results in comminution, articular injury, anterior soft tissue damage, and open injury [2]. A vertical fracture pattern is not uncommon, and the fracture line is usually seen to involve the lateral facet and to lie between the middle and lateral third of the patella [3]. While Boström [1] reported that lateral avulsion was the most common mechanism in 75% of their patients, Dowd [4] reported that direct compression of the patella in a hyperflexed knee was responsible for this kind of fracture. However, there have been a few old reports about lateral marginal fractures of the patella; therefore, we attempted to investigate it based on our experience. This study aimed to define the characteristics of lateral marginal fractures of the patella and evaluate their clinical outcomes. Given the potential impact of reduction quality on patellofemoral mechanics and pain, we hypothesized that anatomical reduction would lead to better functional outcomes compared to nonanatomical reduction. This study further seeks to provide clinically relevant insights to guide optimal surgical management of these rare fractures.

Methods

Ethics Statement

The study was approved by the Institutional Review Board (IRB) of Asan Medical Center (IRB No. 2020-1075) and performed in accordance with the principles of the Declaration of Helsinki. The need for written informed consent was waived because of its retrospective design by the IRB.

We retrospectively reviewed all patients with lateral marginal fractures of the patella in two level I trauma centers from January 2008 to December 2020. A lateral marginal fracture was defined as a longitudinal lateral facet fracture with a fracture line within 15 mm of the lateral patellar border, based on consistent patterns observed in our patient cohort and anatomical considerations related to the lateral facet width. This operational definition was used to distinguish lateral marginal fractures from more central vertical or transverse fractures. The exclusion criteria were fracture with additional transverse component, periprosthetic fractures, and less than 1 year of follow-up.

During the period, a total of 1,131 patellar fractures were screened, and 145 (12.8%) were classified into AO/OTA type B1 (lateral vertical fracture) using computed tomography (CT) images. Moreover, 47 lateral marginal fractures (4.2%) were enrolled, but six patients were excluded because of less than 1 year of follow-up. Finally, 41 patients (31 males and 10 females) were included in the study with an average age of 46.6 years (range, 21–82 years). The average follow-up was 20.5 months (range, 12–52 months). The choice of surgical method was based on fragment size and comminution. Screw fixation was used for adequately sized fragments, tension band wiring (TBW) for smaller or comminuted fragments, and hook plating for selected avulsion-type fractures [5,6]. Patient characteristics and fracture pattern included injury mechanism, open fracture, comminution, distance from the lateral border to the fracture site, initial displacement, and patellar subluxation and treatment method, complication, and functional outcomes. Complications included infection, malunion, and secondary interventions due to persistent pain. The functional outcomes were evaluated with the Lysholm score at 1 year postoperatively.

The clinical outcomes were compared between the anatomical and nonanatomical reduction groups (Table 1). The nonanatomical group was defined as having >1-mm displacement or excision of the fragment. Statistical analysis was performed using IBM SPSS ver. 21.0 (IBM Corp.). Dichotomous data were compared using Fisher exact test, while the independent t-test and Mann-Whitney test were used for the comparison of parametric and nonparametric data, respectively. Statistical significance was set at $P<0.05$.

Table 1. Summary of key clinical and radiological results by reduction type

Variable	Total (n=41)	Anatomical reduction group (n=36)	Nonanatomical reduction group (n=5)
Mean Lysholm score	89.1	90.4	79.8
Functional outcome			
Excellent	25 (61)	23 (63.9)	2 (40)
Good	8 (19.5)	7 (19.4)	1 (20)
Fair	8 (19.5)	6 (16.7)	2 (40)
Poor	0	0	0
Complication			
Malunion	1 (2.4)	0	1 (20)
Persistent pain requiring removal	1 (2.4)	0	1 (20)

Values are presented as number (%).

Results

The injury mechanisms included 34 direct injuries (82.9%) and seven indirect injuries (17.1%). Three patients (7.3%) had open fractures, and 11 (26.8%) had comminuted fractures. The average distance from the lateral border of the patella to the fracture site was 9.9 mm (range, 3–15 mm), and the average displacement was 2.9 mm (range, 2–16 mm). Furthermore, 85% of the patients had the skyline view of the patella at the initial visit, and there was one case of medial patellar subluxation (Fig. 1).

Surgical treatment was performed in all patients, except one. The surgical methods were as follows: 24 cases, screw fixation (Fig. 2); eight, screw fixation combined with TBW; four, TBW; three, fragment removal and retinaculum repair; and one, hook plating (Fig. 1). In one patient with conservative treatment, knee X-ray did not show a fracture, and further evaluation was delayed because he was intubated and cared for in the intensive care unit for polytrauma with small bowel perforation, left clavicle shaft fracture, and mandible open fracture (Fig. 3). One month after injury, he complained of persistent right knee pain, and magnetic resonance imaging (MRI) and CT revealed a lateral marginal fracture.

Anatomical reduction was acquired in 36 cases (88%), but there were five cases (12%) involving nonanatomical reduction (>1-mm displacement and excision of fragment). All cases with internal fixation acquired bone union

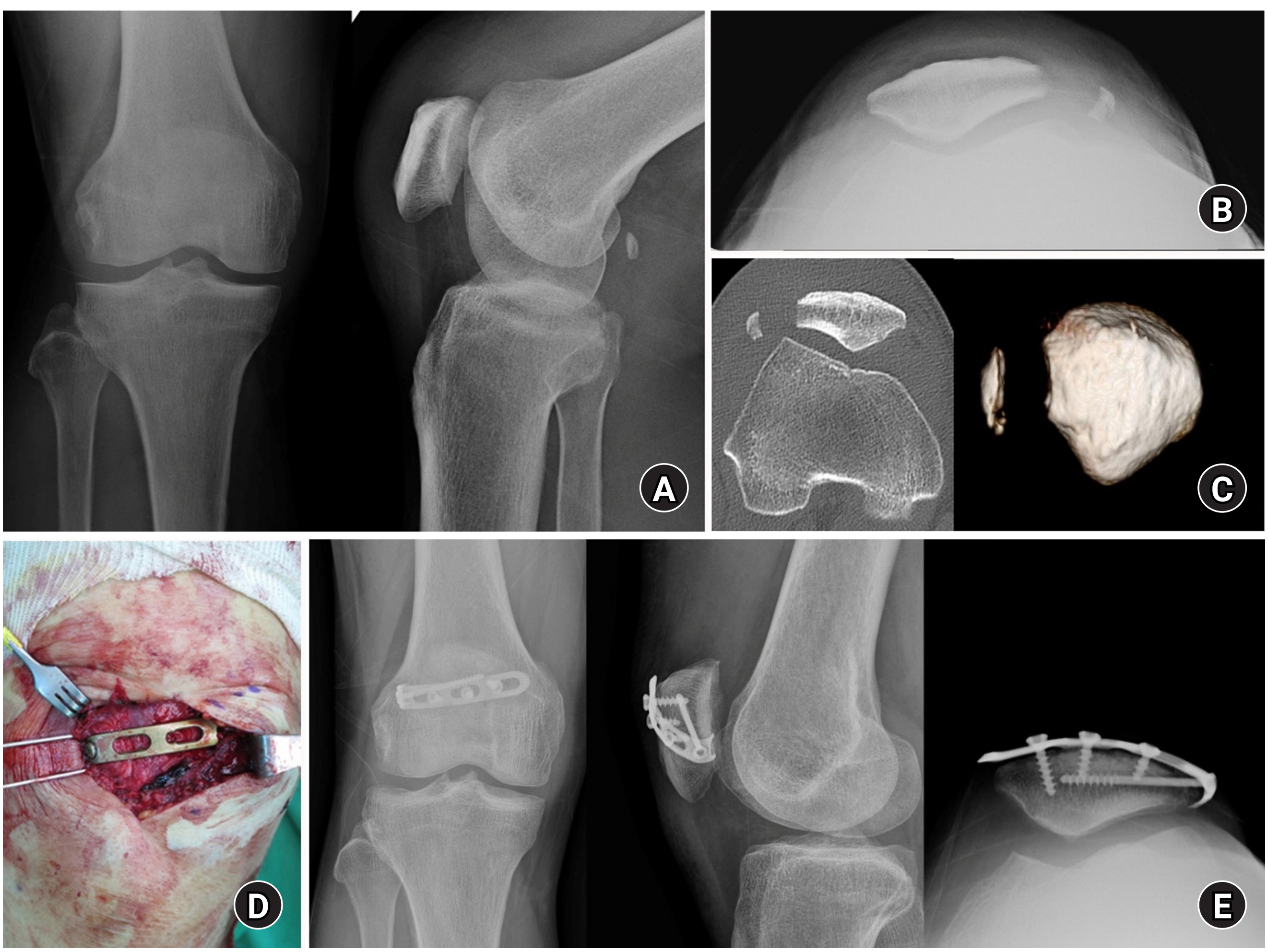

Fig. 1. Lateral marginal fracture with a small fragment. (A) Right knee anteroposterior and lateral views showing no definite fracture. (B) Skyline view revealing medial subluxation of the patella. (C) Knee computed tomography showing a small lateral fragment. (D) Hook plating. (E) Postoperative 1-year X-ray showing union, with a Lysholm score of 94.

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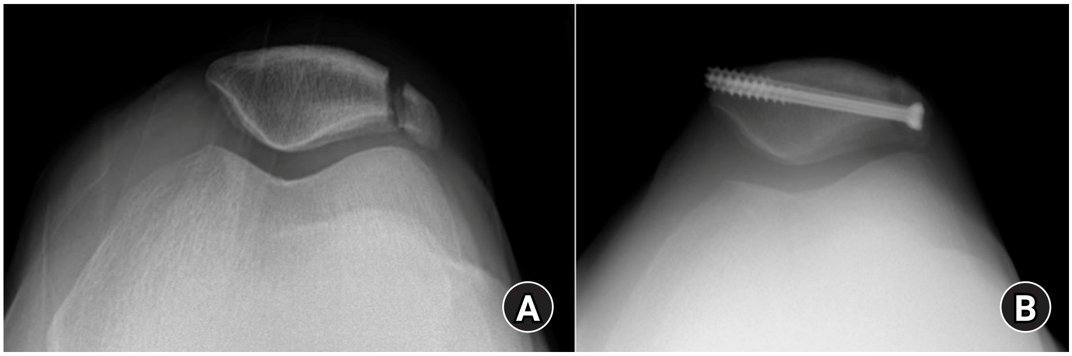

Fig. 2. (A) Lateral marginal fracture. (B) Screw fixation.

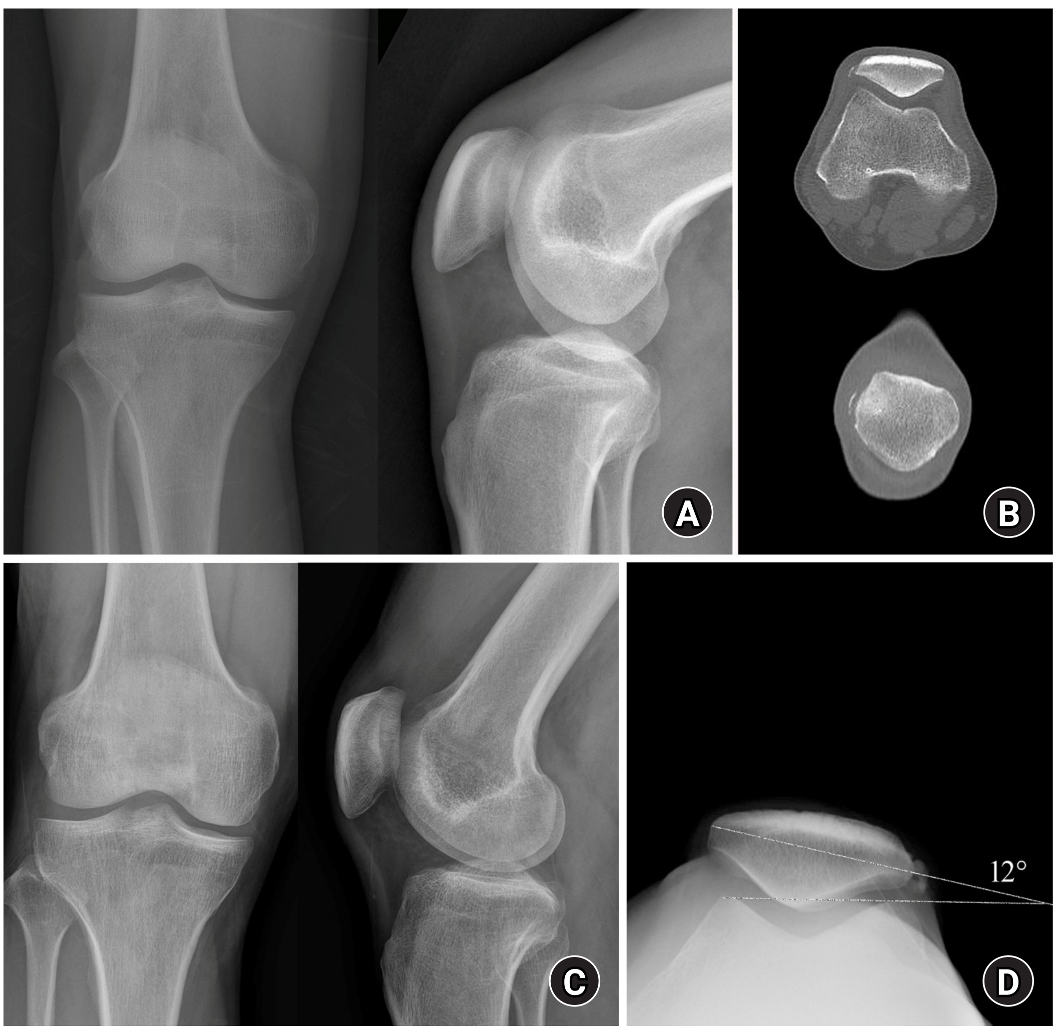

Fig. 3. A 39-year-old male patient. (A) Initial X-ray showing no definite fracture. (B) Computed tomography performed 1 month after injury revealed a tiny fragment at the lateral border of the patella. (C) Postoperative 1-year anteroposterior and lateral views. (D) Skyline view showing the remaining fragment at the lateral border and 12° tilt of the patella, with a Lysholm score of 67.

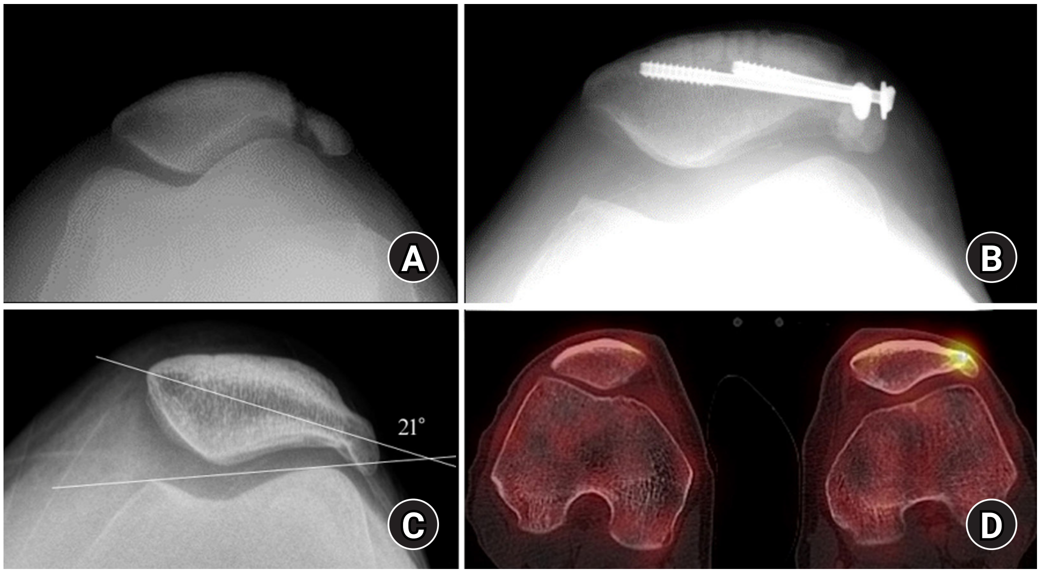

Fig. 4. A 41-year-old male patient. (A) Lateral marginal fracture of the left patella. (B) Displaced fragment after screw fixation. (C) Skyline view showing malunion of the lateral patella and 21° lateral tilt. (D) Bone single-photon emission computed tomography revealing hot uptake at the lateral fragment.

without complications, including infection. The average Lysholm score was 89.1 (range, 67–99): 25 cases (61%), excellent (>90); eight cases (19.5%), good (84–90); eight cases (19.5%), fair (65–83); and 0 case, poor (<65). The nonanatomical reduction group had a poorer functional score (79.8 vs. 90.4; P=0.010). There were five patients in this group: one patient received conservative treatment, another underwent screw fixation, and the others underwent excision. Two cases (40%) of complications were noted, involving malunion and persistent pain that required implant removal. The patient treated by screw fixation had malunion with a laterally displaced fragment and complained of persistent anterior knee pain (Fig. 4). Reoperation for removal was performed, but the pain was persistent. Follow-up knee X-ray after removal showed a 21° lateral tilt of the patella with a “comma sign,” and bone single-photon emission CT findings evidenced the patellofemoral pain. The patient who was managed conservatively also had persistent anterior knee pain with tenderness along the lateral patellar border with a 12° lateral tilt of the patella (Fig. 3). The cause of pain in these two patients was considered as “lateral patellar compression syndrome.”

Discussion

The current study revealed that lateral marginal fractures of the patella were uncommon (4.2%) and most of them (82.9%) were caused by a direct injury. A direct injury to the patella increased the compression force and resulted in a vertical fracture. As the direct force is significantly increasing, the patella would indent the lateral femoral condyle. The history of injury in the current study would support this injury mechanism. An indirect injury on the patella also led to lateral marginal fractures caused by sudden excessive muscle pull compressing the patella onto the lateral femoral condyle, which acted as a fulcrum while the knee was flexed [7]. Another rare pattern is stress fracture (not observed in the current study) caused by middle-distance running or weightlifting, in which strong and repetitive the quadriceps contractions during flexion angles between 20° and 90° could induce compression of the lateral articular facet against the lateral femoral condyle [8,9].

The patellar marginal fractures are uncommon injuries compared with other types [10,11]. The marginal fractures are potentially more common than supposed because it often remain undiagnosed as acute injuries [4]. This fracture often leads to less acute disability than a stellate or transverse fracture, and plain radiographs are often unhelpful.

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In the present study, most of the patients were diagnosed at initial visit, but the diagnosis of one case (2.4%) was delayed 1 month after injury, which was a special case because of unavailability of conversation with the patient and no definite fracture in initial X-ray. However, CT or MRI has been currently performed for patients with knee trauma, and would be helpful to detect marginal fractures [12,13].

In the radiographic review, we found two significant findings: medial patellar subluxation (Fig. 1) and lateral tilt with bone fragment/ossifying tissue along the lateral border of the patella (Figs. 3 and 4). The abnormalities of dynamic muscle strength (vastus medialis obliquus) and static soft tissue restraint (lateral retinaculum) have profound effects on patellofemoral kinematics and may lead to clinical dysfunction [14]. Medial subluxation is uncommon and usually seen after a lateral release surgical procedure [15]. However, as shown in Fig. 1, displaced or inappropriately reduced lateral marginal fracture would lead to medial subluxation. Medial subluxation or dislocation causes patellofemoral pain syndrome [16], and appropriate reduction should be achieved to restore soft tissue tension. Another problem is the "lateral tilt of the patella with ossifying tissue." The newly developed tissue results in aberrant anatomy and ultimately biomechanical abnormalities [14]. The lateral retinaculum also plays an important role in patellofemoral pain syndrome [16]. Injury to the lateral retinaculum, particularly when accompanied by lateral ossifying tissue or a displaced fragment, may result in fibrotic changes and nerve entrapment within the retinaculum. This neuropathic alteration resembles the histopathological features of a Morton neuroma, characterized by perineural fibrosis and nerve irritation [17]. A tilt angle between 0° and 5° is normal, that between 5° and 10° is borderline, and an angle greater than 10° is considered abnormal. In addition, an abnormal tilt was detected in 85% of patients experiencing malalignment pain [18]. It seemed to be a kind of "lateral patellar compression syndrome," which is associated with overload and increased pressure on the lateral facet due to pathologic lateral soft tissue restraints [19]. As shown in Figs. 3 and 4, failure to diagnose or restore marginal fracture of the patella may result in the disability of the knee and potential degenerative changes in the patellofemoral joint.

The current study demonstrated that the postoperative reduction state was related to the functional outcomes. Generally, surgical indications were articular step-off ≥ 1–2 mm and the displacement of articular fragment ≥2–3 mm with the loss of active knee extension [20]. The goals of treatment were as follows: (1) restoration of the extensor mechanism and (2) maintenance of a congruous articular surface [21]. Lateral marginal fractures mainly involve a vertical component and a well-preserved extensor mechanism but are commonly related to articular step-off or displacement. When the reduction was anatomical, the functional outcome was good, while patellofemoral pain, sometimes associated with lateral patellar compression syndrome in the case of failure of reduction, was observed to worsen function. Therefore, such fractures should be managed focusing on anatomical reduction.

The main surgical method was screw fixation, which was useful to secure the fragment firmly but had limitation to small fragment (Fig. 4). For the small fragments, TBW was used in combination or isolation. It is challenging to fix comminuted small fragments, in which excision was one option, and hook plating has been introduced recently for the avulsion fragment [6]. There were several studies about the clinical outcomes of patellar fractures but few results about marginal fracture except inferior pole fractures [6,22,23]. Therefore, further studies about the fixation method and its outcomes are needed.

The limitations of this study include its retrospective nature and the small number of cases. However, the participants were enrolled from a large cohort of 1,131 patellar fractures. Considering the rarity of these fractures, the study findings could be meaningful, even with the small number of cases. In addition, a potential bias may be present because the surgeries were performed at different centers. To overcome this kind of bias, a standard surgical procedure based on basic fracture principles was performed. Despite these limitations, this is a unique study about lateral marginal fractures of the patella and related clinical characteristics.

Conclusions

Lateral marginal fractures of the patella are uncommon injuries, most often caused by direct trauma. These fractures can affect patellofemoral stability and lead to anterior knee pain. In this study, anatomical reduction was associated with better functional outcomes, while nonanatomical reduction was linked to persistent pain. Therefore, we recommend that surgeons should perform anatomical reduction with any fixation method.

Article Information

Author contributions

Conceptualization: JAS, CHK, JWK. Data curation: JAS, CHK, JWK. Formal analysis: JAS, CHK, JWK. Investigation: JAS, JWK. Methodology: JAS, JWK. Project administration: CHK, JWK. Resources: CHK, JWK. Software: CHK. Supervision: CHK, JWK. Validation: CHK, JWK. Visualization: CHK. Writing-original draft: JAS. Writing-review & editing: CHK, JWK. All authors read and approved the final manuscript.

Conflicts of interest

Jae-Ang Sim is the Editor-in-Chief, and Ji Wan Kim is the Deputy Editor of the journal but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflicts of interest relevant to this article were reported.

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Data availability

Contact the corresponding author for data availability.

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Risk factors of surgical complications after use of the femoral neck system: a random forest analysis

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Background: The femoral neck system (FNS), a novel fixation device for managing femoral neck fractures (FNFs), has gained popularity in recent years. However, analyses of the surgical complications and reoperation risks associated with the use of FNS remain limited.
Methods: This retrospective observational study analyzed 57 patients who had undergone FNS fixation for FNF at two university hospitals between July 2019 and February 2024. Demographic, perioperative, and outcome variables, including age, sex, fracture classification (Garden, Pauwels, and AO), implant characteristics, tip-apex distance (TAD), neck shortening, and neck-shaft alignment, were analyzed. In addition to univariate analysis, a machine learning analysis was conducted using a random forest classifier with stratified sampling (80% training, 20% testing). The accuracy, precision, recall, F1-score, and area under the receiver's operating curve were calculated to assess model performance.
Results: Ten patients experienced osteonecrosis of the femoral head (n=6), implant cut-out or penetration (n=3), and peri-implant fracture (n=1). Univariate analysis revealed that the TAD in the complication group was significantly shorter than that in the control group (12.1 vs. 16.7 mm; P=0.012). Additionally, neck shortening in the complication group was greater than that in the control group (4.9 vs. 2.3 mm; P=0.011). The random forest model achieved an accuracy of 83.3% and identified postoperative neck-shaft angle (NSA) as the most important predictor of complications (feature importance, 0.161), followed by bolt length (0.102) and preoperative NSA (0.094).
Conclusions: Risk factor analysis conducted using a random forest model identified postoperative NSA as the most important feature associated with postoperative complications following FNS. Therefore, care should be taken to normalize the postoperative NSA during FNF surgery.
Level of evidence: III.

Keywords: Femoral neck fractures; Femur neck; Femoral neck system; FNS; Complication

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Introduction

Femoral neck fracture (FNF), a prevalent type of orthopedic injury, poses unresolved challenges [1]. The femoral neck system (FNS; DePuy Synthes), introduced for the dynamic fixation of the femoral neck with angular stability, has largely replaced traditional fixation methods. Compared with multiple cannulated cancellous screws (CCS), FNS facilitates the achievement of stronger fixation owing to the presence of the screw-plate construct [2]. Furthermore, the integration of a blade and an anti-rotation screw in this method enhances the axial and rotational stability [3]. In contrast to dynamic hip screws (DHS), the FNS technique involves minimal soft tissue stripping. Thus, it is a minimally invasive technique with a reduced risk of bleeding [4,5].

FNF classified as Pauwel types 1 and 2 were fixed with three CCS as a minimally invasive strategy initially. In contrast, FNF classified as Pauwel type 3 were fixed with an angular stable device to overcome shear force caused by the vertical fracture line. Because FNS provides angular stability with minimally invasive feature [2], theoretically, it can be used for the management of all Pauwel types.

Several studies have compared FNS with traditional fixation implants [2,4-7]. However, to the best of our knowledge, studies exploring the complications associated with FNS are limited. Therefore, this study used the random forest technique, a machine learning method, to identify the factors associated with the incidence of complications following surgical fixation with FNS.

Methods

Ethics Statement

The study was approved by the Institutional Review Board (IRB) of Asan Medical Center (Asan Institute for Life Science, IRB No. 2016-0932) and performed in accordance with the principles of the Declaration of Helsinki. The need for written informed consent was waived by the IRB.

Study Population

The medical records of patients aged ≥18 years who had presented to two university teaching hospitals with FNFs between July 2019 and February 2024 were retrospectively analyzed in this retrospective observational study. Only patients who had undergone surgical treatment using FNS were included in the present study. Patients who presented with pathologic or neglected fractures were excluded. Finally, 57 patients were included in the analysis. The patients were divided into two groups, the control and complication groups, according to the presence of complications—specifically, osteonecrosis of the femoral head (ONFH), nonunion, and peri-implant fracture—in univariate analysis.

Study Variables

The demographic data, perioperative profiles, and postoperative and radiographic outcomes were evaluated to identify the risk factors for the incidence of complications following the fixation of FNS.

The demographic characteristics evaluated included age, sex, fracture site, mechanism of injury, body mass index (BMI), smoking, Charlson comorbidity index (CCI) [8], American Society of Anesthesiologists (ASA) classification [9], preoperative Koval score [10], Garden type [11], Pauwels classification [12], AO classification [13] and follow-up length.

The perioperative profiles and outcomes evaluated comprised the time to surgery, length of stay, implant profile, the position of the bolts, neck-shaft alignment, tip-apex distance (TAD), neck shortening, and complications. The implant profile included the number of plate holes and the length of the bolt. The bolt position was measured in the anteroposterior (AP) and lateral views [14]. The bolt position in the AP view was classified as follows: superior, center, and inferior. The bolt position in the lateral view was classified as follows: anterior, center, and posterior. The preoperative neck-shaft angle (NSA), postoperative NSA [15], and deviation in the Garden alignment index (GAI) [16] were measured to determine the neck-shaft alignment. GAI was measured by the angle between trabecular line in the femoral head and the longitudinal axis of the femoral shaft's medial cortex. The difference between the affected and contralateral sides was defined as the deviation of GAI, which was used to evaluate the quality of fracture reduction.

The TAD was measured in the AP and lateral views, and the sum of the TAD values in both views was calculated using the methods described by Geller et al. [17]. Neck shortening at the final follow-up visit was measured using the methods described by Zheng et al. [7]. As described in the methods of Geller et al. [17] and Zheng et al. [7], the magnification of radiographs was considered when measuring the TAD and neck shortening with the diameter of the bolt fixed at 10 mm. Complication was evaluated as ONFH, nonunion, and peri-implant fracture during the follow-up period. For cases of ONFH, the presence of sclerotic lesions was assessed on simple AP and translateral radiographic views up to the final follow-up visit. If ONFH of Ficat-Arlet classification stage I [18] or higher was suspected, additional magnetic resonance imaging (MRI) was performed to confirm the lesion. Nonunion was defined as fixation failure, characterized by implant breakage, loss of reduction, or a persistent fracture line visible on radiographs at a minimum of 6 months postoperatively. The incidence of complications such as ONFH, cut-out or through penetration, and peri-implant fracture during the follow-up period was evaluated.

Statistical Analysis

Univariate analysis was conducted using SPSS ver. 23.0 (IBM Corp.). Categorical variables were assessed using the chi-square test or Fisher exact test, whereas categorical variables were assessed using the independent t-test. Continuous data are presented as the means and standard deviations. Statistical significance was set at $P<0.05$. Bonferroni correction was applied for multiple comparisons.

The machine learning method random forest was implemented using Python programming language (ver. 3.8, Python Software Foundation) for risk factor analysis [19-21]. The analysis aimed to identify the key predictors associated with complications. Age, sex, fracture site, mechanism of injury, BMI, smoking, CCI, ASA, preoperative Koval score, Garden type, Pauwels type, AO classification, time to surgery, length of hospital stay, implant profiles, bolt position, neck-shaft alignment, TAD, and neck shortening were included as independent variables. This left a set of variables that represent potential demographic, procedural, and clinical factors contributing to complications. A stratified sampling approach was used to split the dataset into training (80%) and testing (20%) subsets. This approach ensured that both classes of the target variable (complication, 1 and complication, 0) were proportionally represented in each subset.

A random forest classifier comprising 100 decision trees with default hyperparameters was employed. The Gini impurity criterion was used to optimize node splits, thereby maximizing the class purity within each split. The feature importance scores were computed based on the mean decrease in impurity across all decision trees to facilitate the identification of the variables most strongly associated with the outcome. A comprehensive set of metrics, encompassing accuracy, precision, recall, F1 score, and area under the receiver's operating curve (ROC-AUC), was used to assess model performance.

Results

Univariate Analysis

The control and complication groups comprised 47 and 10 patients, respectively (Table 1). Comparisons are presented as 'control vs. complication group' throughout the manuscript. No significant differences were observed between the groups in terms of age (58.0±14.0 vs. 55.1±11.2; P=0.542), distribution of female patients (62% and 50%; P=0.504), or other demographic data such as injury mechanism, BMI, smoking, CCI, ASA, preoperative Koval score, and follow-up length. Severe type of fracture pattern (Garden type 3 and 4, 41% vs. 70%; Pauwels type 3, 47% vs. 60%) was more prevalent in the complication group; however, the differences did not reach statistical significance.

Table 2 presents the perioperative profile and outcomes. No significant differences were observed between the groups in terms of time to surgery or length of stay. Similarly, no significant differences were observed between the groups in terms of the number of holes (2-hole, 30% vs. 40%; P=0.709) or bolt length (86.0±7.1 vs. 91.5±12.0; P=0.189). The bolt was positioned at the center in the AP view in 70% and 50% of cases in the control and complication groups, respectively (P=0.193). The bolt was positioned at the center in the lateral view in 87% and 90% of cases in the control and complication groups, respectively (P=0.530). In addition to greater GAI deviation (4.3±4.4 vs. 9.5±11.1; P=0.177), greater preoperative (137.6°±12.0° vs. 134.9°±12.0°; P=0.514) and postoperative (135.8°±5.6° vs. 132.8°±16.7°; P=0.595) varus-NSA were observed in the complication group; however, these differences did not reach statistical significance. The TAD in the AP view (8.4±2.6 mm vs. 5.9±2.3 mm; P=0.008) and the sum of TAD (16.7±5.3 mm vs. 12.1±4.0 mm; P=0.012) were significantly lower in the complication group. Greater neck shortening was observed in the complication group (2.3±3.0 mm vs. 4.9±2.3 mm; P=0.011). ONFH, cut-out or through penetration, and peri-implant fracture were observed in six patients, three patients, and one patient, respectively (Table 3).

Surgical Complication Analysis

The random forest model achieved moderate performance in predicting the incidence of complications, with an accuracy of 83.3%. The model achieved a precision of 50.0%, indicating that only half of the predicted positive cases

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Table 1. Demographic data and fracture characteristics

Characteristic	Control group (n=47)	Complication group (n=10)	P-value
Age (yr)	58.0±14.0	55.1±11.2	0.542
Female sex	29 (62)	5 (50)	0.504
Left side	21 (45)	6 (60)	0.492
Mechanism of injury			0.447
Simple fall	30 (64)	9 (90)	
Fall from height	12 (25)	1 (10)	
Motor vehicle crash	5 (11)	0 (0)	
BMI (kg/m^2)	21.8±3.1	22.5±3.2	0.481
Smoker	7 (15)	2 (20)	0.650
CCI			0.539
0–3	30 (64)	6 (60)	
4–6	13 (28)	2 (20)	
7–9	4 (8)	2 (20)	
ASA			0.744
I	16 (34)	2 (20)	
II	21 (45)	6 (60)	
III	10 (21)	2 (20)	
Koval score[a]			0.482
1	26 (55)	6 (60)	
2	4 (9)	0 (0)	
3	2 (4)	0 (0)	
4	0 (0)	1 (10)	
5	14 (30)	3 (30)	
6	1 (2)	0 (0)	
Garden type			0.115
1	18 (38)	3 (30)	
2	10 (21)	0 (0)	
3	11 (24)	2 (20)	
4	8 (17)	5 (50)	
Pauwels type			0.556
1	7 (15)	0 (0)	
2	18 (38)	4 (40)	
3	22 (47)	6 (60)	
AO classification			0.882
31B1	27 (57)	6 (60)	
31B2	20 (43)	4 (40)	
Follow-up length (mo)	16.4±11.6	20.9±10.0	0.256

Values are presented as mean±standard deviation or number (%).
BMI, body mass index; CCI, Charlson comorbidity index; ASA, American Society of Anesthesiologists.
[a]Preoperative Koval score.

were correct. The model achieved a recall of 50.0%, indicating that some true positive cases were overlooked. The F1 score, which represents the harmonic mean of precision and recall, was 50.0%. This finding indicated that the ability of the model to balance precision and recall was limited. The ROC-AUC score was 0.95, indicating that the model possesses strong discriminative ability. However, the real-world predictive power of the model may have been limited owing to the low recall and precision.

Feature importance analysis identified postoperative

Table 2. Perioperative profiles and outcomes

Variable	Control group (n=47)	Complication group (n=10)	P-value
Time to surgery (day)	0.91±1.0	0.60±0.8	0.366
Length of stay (day)	7.5±9.8	5.6±2.8	0.561
Implant profile			
Number of holes			0.709
1	33 (70)	6 (60)	
2	14 (30)	4 (40)	
Length of bolts	86.0±7.1	91.5±12.0	0.189
Bolt position in AP view			0.193
Superior	1 (2)	1 (10)	
Center	33 (70)	5 (50)	
Inferior	13 (28)	4 (40)	
Bolt position in lateral view			0.530
Anterior	4 (9)	0 (0)	
Center	41 (87)	9 (90)	
Posterior	2 (4)	1 (10)	
Neck-shaft alignment (°)			
Preoperative NSA	137.6±6.2	134.9±12.0	0.514
Postoperative NSA	135.8±5.6	132.8±16.7	0.595
Garden index deviation	4.3±4.4	9.5±11.1	0.177
TAD (mm)			
TAD in AP view	8.4±2.6	5.9±2.3	0.008
TAD in lateral view	8.3±3.1	6.2±3.4	0.054
Sum of TAD	16.7±5.3	12.1±4.0	0.012
Neck shortening (mm)	2.3±3.0	4.9±2.3	0.011

Values are presented as mean±standard deviation or number (%).
AP, anteroposterior; NSA, neck-shaft angle; TAD, tip-apex distance.

Table 3. Complications

Complication type	No. of cases (n=10)
Osteonecrosis of femoral head	6
Cut-out or through	3
Peri-implant fracture	1

NSA (0.161) as the most significant predictor, followed by the length of the bolt (0.102) and preoperative NSA (0.094). A bar chart ranking the 10 most important features was generated to visualize the importance scores, highlighting the relative impact of each variable (Fig. 1).

Discussion

Univariate comparative analysis revealed that a shorter TAD and greater neck shortening were observed in the complication group. However, risk factor analysis using the random forest model identified postoperative NSA as the most important predictor of complications.

Although TAD, neck shortening, and NSA are clinically significant, the postoperative NSA warrants particular attention, given its relationship with other factors. However, the relatively small sample size of the present study complicated the application of the random forest model. Thus, further studies with a larger dataset must be conducted in the future.

Traditionally, classification systems such as the Garden classification system and Pauwels classification system were used to classify FNF [11,12]. However, these classification systems did not exert a statistically significant impact on prognosis in the present study. Pauwels classification helps identify clearer treatment pathways, as vertically oriented fractures (Pauwel type 3) can be managed relatively well by selecting an appropriate fixation construct. DHS

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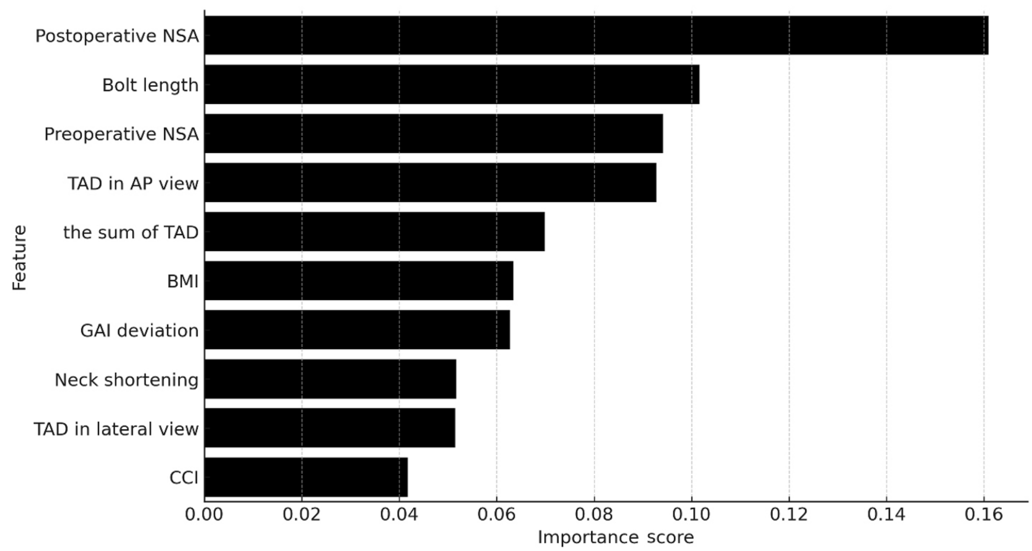

Fig. 1. Top 10 feature importance ranked by the random forest model in predicting complications. NSA, neck-shaft angle; TAD, tip-apex distance; AP, anteroposterior; BMI, body mass index; GAI, Garden alignment index; CCI, Charlson comorbidity index.

and anti-rotation screws, which were traditionally used for its management, have been replaced with FNS in recent years [22]. Garden classification can indicate the disruption of blood supply to femoral neck related with initial injury, which is difficult to address through surgical procedures. Although not statistically significant, the notable discrepancy in the proportion of Garden type 4 fractures (17% vs. 50%) indicates a potential clinical impact, warranting further investigation.

A TAD value of <25 mm was considered in previous studies [17]. Thus, the clinical impact for the TAD value (control vs. complication, 16.7 vs. 12.1 mm) was difficult to interpret in the present study, despite the significant difference observed between the two groups. Nevertheless, the findings of previous studies indicate that the complication and control groups underwent surgery with excellent TAD values. Notably, the TAD in the complication group was lower than that in the control group. Severe fracture types were presumed to contribute to TAD in that surgeons may insist on performing firm fixation to achieve optimal outcomes; however, this approach results in the insertion of the FNS bolt close to the subchondral bone of the femoral head. Zhou et al. [23] reported that a short screw-apex distance may be associated with ONFH. FNS has anti-rotation screws directed to the apex of the femoral head; thus, the short TAD may have influenced the incidence of complications.

Adverse events such as cortical comminution of the severed end, fracture fractionation, and improper reduction may lead to neck shortening after fixation [6]. This observation indicates that neck shortening is associated with the incidence of complications. However, neck shortening cannot be detected immediately after surgery; it becomes apparent over a period of weeks to months. Thus, care should be taken to minimize the risk of neck shortening during FNS surgery.

Univariate analysis revealed no significant differences between the groups in terms of the postoperative NSA. However, risk factor analysis conducted using the random forest model identified postoperative NSA as the most important feature (0.161), suggesting a strong relationship between this anatomical measurement and the incidence of complications. In situ fixation is sometimes performed during osteosynthesis in cases with stable fractures such as Garden type I or II. However, the quality of reduction plays a crucial role in improving the poor prognosis associated with unstable FNFs [24]. Unstable FNFs are inherently associated with a higher risk of complications than stable FNFs; thus, postoperative NSA is one of the few modifiable factors in the osteosynthesis process for unstable FNFs [25]. Subtle variations in the alignment influence the biomechanical stability and stress distribution [26]. Therefore, care should be taken to normalize the postoperative NSA during FNF surgery.

This study has certain limitations. First, the relatively small sample size may have led to the low model performance score of the random forest model. In particular, there was a discrepancy between the results of the univariate analysis and the random forest model. While this can be attributed to the fundamental differences between the two analytical approaches, we acknowledge that the small sample size in our study may have limited the reliability of the random forest analysis. Further studies with larger sample sizes must be conducted to address this limitation. Second, variables with relatively lower importance were also considered owing to the retrospective study design. This may have affected the modeling process. Although this is a strength of the random forest model, the results must be interpreted with caution in conjunction with sample size considerations. Third, the follow-up period was short and inconsistent. This may have limited the detection of long-term complications and introduced variability in outcome assessment. Thus, cases with sufficient and consistent follow-up must be selected in future studies. Fourth, malunions such as varus deformity and femoral neck shortening were not specifically classified as complications, despite their potential to cause clinical problems. Although the degree of reduction was evaluated using the GAI deviation (9.5° in the complication group vs. 4.3° in the control group), a more detailed analysis focusing on malunion-related outcomes may provide additional clinical insights in future studies. In addition, not all patients were screened with MRI for ONFH among the complications as routinely, which may also have led to underestimation. According to previous studies, the incidence of asymptomatic ONFH that cannot be identified on plain radiographs after FNFs has been reported to be as high as 34.2% [27]. Further research is warranted to investigate this issue.

Conclusions

Risk factor analysis conducted using the random forest model identified postoperative NSA as the most important feature for postoperative complications following FNS. Therefore, care should be taken to normalize the postoperative NSA during FNF surgery.

Article Information

Author contributions

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

Conflicts of interest

Ji Wan Kim is the Deputy Editor of the journal but was not involved in the peer reviewer selection, evaluation, or decision process of this article. No other potential conflicts of interest relevant to this article were reported.

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Data availability

Contact the corresponding author for data availability.

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Author correction: "Comparison of outcomes of reinforced tension band wiring and precontoured plate and screw fixation in the management of Mayo type IIIB olecranon fractures"

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Correction

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In the article titled "Comparison of outcomes of reinforced tension band wiring and precontoured plate and screw fixation in the management of Mayo type IIIB olecranon fractures" [1], two numerical errors were found in the Abstract that require correction.

On lines 7–8, "Of these, 11 patients underwent reinforced TBW, and 13 received precontoured PF" has been corrected to "Of these, 13 patients underwent reinforced TBW, and 11 received precontoured PF." This correction reflects the actual group sizes used in the statistical analysis, consistent with Table 1 and the rest of the manuscript.

On lines 18–19, "Reoperations were required in 15.8% of the reinforced TBW group due to hardware irritation" has been corrected to "Reoperations were required in 7.7% of the reinforced TBW group due to hardware irritation." This correction reflects the accurate number of reoperations (1 out of 13 patients), consistent with Table 3 and the Results section on page 99.

These corrections are limited to the Abstract and do not affect the study's results, statistical interpretations, or overall conclusions. The authors sincerely thank the readers and editors for their attention to this matter.

Reference

1. Kang HG, Lee TJ, Won SJ. Comparison of outcomes of reinforced tension band wiring and precontoured plate and screw fixation in the management of Mayo type IIIB olecranon fractures. J Musculoskelet Trauma 2025;38:96-101.

Instructions for authors

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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, reviews, letters to the editor, and editorial, and other types.
- Original Article: 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.
- 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.
- Editorial: 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 Review: Systematic review examines published material on a clearly described subject in a systematic way. There must be a description of how the evidence on this topic was tracked down, from what sources and with what inclusion and exclusion criteria.
- Meta-Analysis: A systematic overview of studies that pools the results of two or more studies to provide an overall answer to a research question or interest. Summarizes quantitatively the evidence regarding a treatment, procedure, or association.

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
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 an abstract, tables, figures, acknowledgments, and references.

Format of Manuscript Title page

- The title page must include the title, the authors' names, academic degrees, 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.
- 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/).
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- Funding: All sources of funding for the study should be stated here explicitly.
- Acknowledgments: Any persons who contributed to the study or manuscript but do not meet the criteria for authorship should be acknowledged here. If you do not have anyone to acknowledge, please write "None" in this section.

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. Under 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 ob-

- tained 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 in the last paragraph of the discussion.
- Conclusions: Briefly state the answer to your question or hypothesis in the Introduction. Describe carefully to draw conclusions only from your results and verify that your data firmly support your conclusions. The conclusions in the text and those in the abstract must have the same content.
- 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 indi-

cated as "Fig." and "Table." For example, "Magnetic resonance imaging of the brain revealed... (Figs. 1-3).

References

- The number of references is recommended to be 30 for original articles.
- 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."
- Authors should be listed by surname followed by initials.
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- Examples of references are as follows:

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.

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  *P< 0.05, **P< 0.01, ***P< 0.001.
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7. MANUSCRIPT PROCESSING AFTER ACCEPTANCE

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History

Revised on

- January 1, 1999
- January 1, 2006
- November 1, 2006
- April 28, 2008
- July 1, 2008
- February 1, 2012
- July 1, 2012
- July 1, 2016
- March 1, 2019
- September 1, 2020
- August 6, 2024
- December 20, 2024

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- ☐ 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.
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