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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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Original Articles

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Current concepts and applications of bone graft substitutes in orthopedic surgery

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Bone defects, which often arise from high-energy injuries, infections, tumor resections, or nonunions, represent a persistent challenge in orthopedic trauma surgery. Autologous bone grafting remains the gold standard due to its unique combination of osteogenic, osteoinductive, and osteoconductive properties. However, issues such as donor site morbidity, limited graft volume, and increased surgical time have driven the development of bone graft substitutes. These substitutes vary widely in origin, composition, biological activity, and mechanical characteristics, encompassing allografts, xenografts, synthetic materials, and biologically enhanced constructs. This review outlines the fundamental biological principles underlying bone regeneration—including osteogenesis, osteoinduction, and osteoconduction—and addresses additional key factors such as biocompatibility, biodegradability, and mechanical strength. Current bone graft materials are classified by biological origin and functional characteristics, with an emphasis on their use in trauma surgery. Particular attention is given to the clinical applications, indications, and limitations of allograft-based solutions (such as structural allografts and demineralized bone matrix), synthetic ceramics (including calcium phosphate and bioactive glass), and biologically enhanced options, such as recombinant growth factors and stem cell therapies. In trauma settings, graft selection must be tailored to the characteristics of the defect, mechanical demands, the biological environment, and patient-specific factors. Integration with surgical technique and fixation is crucial for optimizing outcomes. Although modern substitutes show promise, none fully replicate the complex biology of autografts. Looking ahead, emerging technologies such as 3D printing, nanotechnology, and smart biomaterials offer exciting possibilities but face translational challenges. This review aims to provide practicing orthopedic surgeons with a concise, evidence-based overview of bone substitute options and their roles in trauma care. By applying core biological principles and clinical judgment, surgeons can better navigate the expanding array of graft materials to improve outcomes for patients with complex skeletal defects.

Keywords: Bone substitutes; Bone regeneration; Fracture healing; Biocompatible materials

Review Article

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Introduction

Background

The management of bone defects presents one of the most challenging aspects of contemporary orthopedic practice [1,2]. These defects, whether arising from high-energy trauma, oncological resection, infectious processes, or developmental anomalies, often require sophisticated reconstructive approaches to restore both structural

integrity and functional capacity. The complexity of these cases has intensified as our understanding of bone biology has evolved, yet the fundamental challenge remains: how to effectively replace lost bone tissue while minimizing patient morbidity [3,4].

For decades, autologous bone grafting has dominated the field as the undisputed gold standard. Its success stems from the unique combination of osteogenic cells, inductive growth factors, and conductive matrix that no other material can fully replicate. However, the clinical reality often falls short of this theoretical ideal. Donor site complications affect up to 20% of patients, ranging from minor discomfort to chronic pain syndromes. The available volume is frequently inadequate for large defects, and the additional surgical time and blood loss can be prohibitive in compromised patients [4,5].

This clinical dilemma has catalyzed decades of research into alternative materials. The result is a diverse landscape of bone substitutes, each with distinct properties and applications [6,7]. From the early use of processed cadaveric bone to sophisticated bioengineered constructs, the field has witnessed remarkable innovation. Yet this diversity also creates confusion for practicing surgeons who must navigate an increasingly complex array of options [8,9].

Objectives

The purpose of this review is to provide a practical framework for understanding bone graft substitutes in the context of orthopedic trauma surgery. Rather than presenting an exhaustive catalog of available materials, we focus on the fundamental principles that govern their selection and use, emphasizing clinical relevance over theoretical considerations.

Ethics statement

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

Biological foundations of bone grafting

The triad of bone regeneration

Successful bone grafting depends on three interconnected biological processes that work in concert to restore skeletal integrity. Understanding these mechanisms is crucial for rational graft selection and realistic outcome expectations (Table 1).

Osteogenesis represents the direct contribution of viable bone-forming cells to the healing process. These cells, primarily osteoblasts and their precursors, are capable of synthesizing new bone matrix immediately upon implantation. This mechanism is unique to autologous grafts, where living cells survive the transplantation process and contribute directly to bone formation. The osteogenic potential of autograft explains its superior performance in challenging clinical scenarios, particularly when host biology is compromised [1,5].

Osteoinduction involves a more complex cascade of cellular events. Growth factors and bioactive molecules within the graft material recruit host mesenchymal stem cells and stimulate their differentiation into bone-forming cells. This process is mediated by members of the bone morphogenetic protein (BMP) family, along with other signaling molecules such as transforming growth factor-beta and insulin-like growth factors. The osteoinductive capacity of a material depends largely on the preservation of these proteins during processing, which explains the variability in clinical performance among different preparations [10,11].

Osteoconduction provides the structural framework for

Table 1. Biological properties of bone graft materials

Property	Definition	Key example
Osteogenesis	Contribution of living cells to new bone formation	Autograft
Osteoinduction	Induction of osteoprogenitor cells to differentiate into osteoblasts	DBM, BMP-2
Osteoconduction	Passive scaffold for new bone ingrowth	Allograft, ceramics
Biocompatibility	Lack of immune reaction or toxicity	Most clinical substitutes
Biodegradability	Resorption in synchrony with bone formation	Calcium sulfate, β-TCP
Mechanical support	Ability to withstand load-bearing forces	Structural allografts, some ceramics

DBM, demineralized bone matrix; BMP-2, bone morphogenetic protein-2; β-TCP, beta-tricalcium phosphate.

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bone regeneration. The graft material serves as a three-dimensional scaffold that facilitates cell migration, vascular ingrowth, and subsequent bone deposition. This mechanism is perhaps the most predictable and is shared by most bone substitutes, regardless of their origin. However, the effectiveness of osteoconduction depends on factors such as pore size, interconnectivity, and surface chemistry, which vary significantly among different materials [3,7].

Beyond the classical triad

While the traditional triad provides a useful framework, modern bone grafting must also consider additional factors that influence clinical success. Biocompatibility extends beyond simple tissue acceptance to encompass the complex interplay between the graft material and the host immune system. Some materials may trigger chronic inflammatory responses that ultimately compromise healing, while others may be rapidly cleared by macrophages before meaningful bone formation can occur [12,13].

Biodegradability presents a delicate balance between mechanical support and biological remodeling. The ideal graft material should be gradually replaced by new bone tissue, but the timing of this replacement is critical. Premature degradation can lead to mechanical failure, while persistence of non-resorbing material may interfere with normal bone remodeling and create long-term complications [3,14].

Mechanical properties become particularly important in load-bearing applications. The graft must provide adequate strength to withstand physiological forces while maintaining porosity for vascular ingrowth. This represents a fundamental engineering challenge, as these requirements are often contradictory. Dense materials may offer superior strength but poor vascularization, while porous materials may facilitate healing but lack mechanical integrity [9].

Classification systems

The traditional classification of bone grafts based on their biological origin—autograft, allograft, xenograft, and synthetic—remains useful but increasingly oversimplified. Modern materials often combine elements from multiple categories, creating hybrid products that defy simple categorization (Table 2) [6,7].

Autografts continue to represent the biological gold standard, despite their limitations. The harvest site significantly influences graft properties, with cancellous bone from the iliac crest offering superior osteogenic potential compared to cortical bone from the fibula. However, even autografts exhibit variability based on patient age, health status, and harvest technique [1,5].

Allografts have evolved far beyond simple cadaveric bone transplantation. Modern processing techniques can selectively preserve or remove specific components, creating materials with tailored properties. Fresh-frozen allografts retain some osteoinductive capacity but carry higher immunological risk, while freeze-dried preparations offer improved handling characteristics at the cost of reduced biological activity [2,4,15].

Xenografts remain controversial, with significant variation in acceptance across different regions and cultures. Despite extensive processing to remove cellular components, concerns about immunogenicity and disease transmission have limited their widespread adoption in orthopedic applications [8].

Synthetic materials represent the most diverse category, ranging from simple calcium phosphate ceramics to complex composite structures. The advantage of synthetic materials lies in their consistency and unlimited availability, but they generally lack the biological activity of natural grafts [7,9].

Table 2. Summary of common bone graft substitutes

Type	Source	Biological activity	Mechanical strength	Common use case
Autograft	Patient	Osteogenesis, induction, conduction	High	All types of defects
Allograft	Human donor	Osteoconduction, weak induction	Variable	Large defects, structural support
Xenograft	Animal	Mainly osteoconduction	Low–moderate	Void filling, dental/maxillofacial
Synthetic ceramic	Synthetic	Osteoconduction (some osteoinduction *in vitro*)	Variable	Void filler, non-load-bearing defects
Bioactive glass	Synthetic	Osteoconduction + surface stimulation	Low	Infection-prone or irregular cavities
BMP-enhanced	Biologic	Strong osteoinduction	Not applicable	Fusion promotion, difficult healing sites

BMP, bone morphogenetic protein.

Contemporary bone substitute materials

Allograft-based solutions

The use of human cadaveric bone has a long history in orthopedic surgery, but modern allograft processing has transformed these materials into sophisticated biological tools. Structural allografts continue to play a crucial role in reconstructive surgery, particularly for large segmental defects where mechanical support is paramount. These grafts undergo processing to reduce immunogenicity while preserving mechanical properties, but they lack the cellular components necessary for osteogenesis [2,15].

The incorporation of structural allografts follows a predictable pattern that differs significantly from autograft healing. Initial mechanical support is provided by the processed bone matrix, but gradual remodeling occurs through creeping substitution. This process can take years to complete and may never fully restore the mechanical properties of native bone. Nevertheless, structural allografts remain invaluable for specific applications where alternatives are limited [4].

Demineralized bone matrix (DBM) represents a more processed form of allograft with distinct properties and applications. The demineralization process removes the mineral component while preserving the organic matrix, including growth factors responsible for osteoinduction [16]. However, the biological activity of DBM varies considerably based on donor characteristics, processing methods, and storage conditions. This variability has led to the development of numerous commercial preparations, each with distinct handling characteristics and claimed biological activities. The clinical performance of DBM depends heavily on the host environment and the specific preparation used. In well-vascularized sites with good biological potential, DBM can stimulate significant bone formation. However, in compromised environments, its effectiveness may be limited. The addition of various carriers and enhancers has attempted to improve consistency, but clinical outcomes remain somewhat unpredictable [12].

Synthetic alternatives

The development of synthetic bone substitutes has been driven by the desire to create materials with predictable properties and unlimited availability. Calcium phosphate ceramics represent the most mature category of synthetic bone substitutes, with decades of clinical experience supporting their use [3,7]. Hydroxyapatite (HA) closely mimics the mineral component of natural bone, providing excellent biocompatibility and osteoconductive properties. However, its slow resorption rate means that it may persist in the body for years, potentially interfering with normal bone remodeling [6]. This characteristic makes HA suitable for applications where long-term structural support is desired, but problematic when rapid incorporation is needed.

Beta-tricalcium phosphate (β-TCP) offers a more favorable resorption profile, with gradual dissolution that more closely matches the rate of new bone formation. This property makes it attractive for applications where complete replacement by host bone is desired. However, the mechanical properties of β-TCP are generally inferior to HA, limiting its use in load-bearing applications [3].

Biphasic calcium phosphate attempts to combine the advantages of both materials by incorporating both HA and β-TCP in a single product. The ratio of these components can be adjusted to tailor the resorption characteristics to specific clinical needs. Despite this theoretical advantage, clinical studies have not consistently demonstrated superior performance compared to single-phase materials [7].

Bioactive glass represents a different approach to synthetic bone substitutes, with the ability to form direct chemical bonds with bone tissue. The dissolution of bioactive glass creates a locally alkaline environment that may stimulate osteoblast activity while inhibiting bacterial growth. These properties make bioactive glass potentially attractive for infected or contaminated sites, although clinical experience remains limited compared to calcium phosphate ceramics [8].

Biologically enhanced materials

The limitations of purely synthetic materials have led to the development of biologically enhanced substitutes that combine synthetic scaffolds with biological components. BMPs represent the most clinically significant example of this approach [10,11].

Recombinant human BMP-2 (rhBMP-2) has demonstrated remarkable osteoinductive capacity in clinical trials, with the ability to stimulate bone formation even in challenging biological environments. The mechanism involves recruitment of mesenchymal stem cells and their differentiation into osteoblasts through well-characterized

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signaling pathways. However, the clinical experience with rhBMP-2 has been mixed, with concerns about dose-dependent side effects and cost-effectiveness limiting its widespread adoption [10,17]. The delivery system for BMPs is as important as the growth factor itself. Collagen sponges provide a biocompatible carrier that allows for localized delivery, but the release kinetics may not be optimal for all applications. Alternative delivery systems, including synthetic polymers and ceramic matrices, are being investigated to improve the efficacy and safety profile of BMP-based products.

Stem cell-based approaches represent an emerging frontier in bone grafting, with the potential to provide autologous osteogenic cells without the morbidity of bone harvest [18]. Mesenchymal stem cells can be harvested from various sources, including bone marrow, adipose tissue, and peripheral blood, then expanded in culture and delivered on appropriate scaffolds [18,19]. However, the clinical translation of stem cell therapies faces significant regulatory and practical challenges.

Platelet-rich plasma (PRP) and related blood-derived products have gained popularity as adjuncts to bone grafting procedures. The theoretical rationale is compelling, as these products contain concentrated growth factors and cytokines that may enhance healing. However, the clinical evidence for PRP in bone grafting remains inconsistent, with significant variation in preparation methods and outcome measures complicating interpretation of results [20].

Clinical applications in trauma surgery

Defining clinical indications

The decision to use bone substitutes in trauma surgery requires careful consideration of multiple factors that extend beyond simple defect size (Table 3). Segmental bone loss remains the most straightforward indication, particularly when the defect exceeds 2-3 cm in length or when autograft volume is insufficient [2]. However, the definition of "critical size defect" varies with location, patient age, and biological environment [1].

Metaphyseal defects present unique challenges that often favor the use of bone substitutes. These defects commonly occur in periarticular fractures where subchondral support is crucial for joint congruity [21,22]. The cancellous bone environment is generally favorable for graft incorporation, but the mechanical demands require materials that can provide immediate structural support [7].

Nonunion management represents a complex clinical scenario where bone substitutes may play a crucial role. The biological environment in established nonunions is often compromised, with poor vascularity and fibrous tissue formation. In such cases, the choice of bone substitute must consider both the need for biological stimulation and the mechanical requirements for stability [14].

Infection-related bone loss poses particular challenges for bone substitute selection. The presence of bacteria or their biofilms can compromise graft incorporation and lead to persistent infection. Some materials may be more susceptible to bacterial colonization than others, and the timing of grafting relative to infection control becomes critical [20].

Patient-specific considerations

The selection of bone substitutes must be individualized based on patient characteristics that influence healing potential. Age significantly affects both the biological response to grafts and the mechanical demands placed on them [5]. Elderly patients may have reduced osteogenic potential but also lower functional demands, while young patients may require materials that can withstand high ac-

Table 3. Clinical considerations in choosing bone graft substitutes

Clinical scenario	Preferred graft type	Key consideration
Small metaphyseal defect	Allograft, synthetic ceramic	Osteoconduction sufficient; low load-bearing
Large segmental defect	Autograft±BMP, structural allograft	Mechanical strength needed; consider augmentation
Poor bone healing potential	BMP-enhanced, DBM	Requires osteoinduction
Infection-prone area	Bioactive glass, antibiotic-loaded graft	Antimicrobial activity desirable
Pediatric case	BMP should be avoided; autografts or resorbables are used instead	Safety concerns with growth
Revision surgery or fusion failure	BMP-2, autografts	High induction needed

BMP, bone morphogenetic protein; DBM, demineralized bone matrix.

tivity levels [19].

Comorbidities such as diabetes, smoking, and immunosuppression can profoundly impact graft performance. These conditions may compromise the biological response to osteoinductive materials while also affecting the mechanical properties of healing bone [4,16]. In such cases, the choice of bone substitute may need to favor materials with proven performance in compromised hosts [13].

Anatomical location influences both the mechanical requirements and the biological environment for graft incorporation. Weight-bearing sites require materials with superior mechanical properties, while non-weight-bearing locations may prioritize biological activity over structural strength [9]. The local vascularity and soft tissue coverage also affect the choice of appropriate materials [12].

Integration with surgical technique

The success of bone substitutes depends heavily on their integration with sound surgical principles. Mechanical stability remains paramount, as even the most biologically active graft will fail without adequate fixation [3]. The choice of fixation method should consider the properties of the graft material and the expected timeline for incorporation [3,20].

Soft tissue management becomes particularly important when using bone substitutes, as these materials may be more susceptible to infection or extrusion compared to autograft. Adequate soft tissue coverage and tension-free closure are essential for successful outcomes [20].

Timing considerations may favor staged procedures in contaminated or infected cases. The biological environment must be optimized before grafting, which may require debridement, antibiotic therapy, or other preparatory measures [10]. The use of temporary spacers or external fixation may be necessary to maintain alignment and stability during the preparatory phase [14].

Outcome expectations

The clinical performance of bone substitutes must be evaluated within the context of realistic expectations. Time to union may be prolonged compared to autograft, particularly for materials that rely primarily on osteoconduction [3]. Patients should be counseled about the expected timeline for healing and the potential need for protected weight-bearing [5].

Functional outcomes may differ from those achieved with autograft, particularly in load-bearing applications. While bone substitutes may achieve radiographic union, the mechanical properties of the healed bone may not fully restore normal function [9]. This consideration is particularly important in young, active patients with high functional demands [19].

Complication rates vary significantly among different bone substitute materials and clinical applications. Some materials may have higher rates of infection, delayed union, or failure compared to autograft. These risks must be weighed against the potential benefits of avoiding donor site morbidity [15,16].

Future directions and emerging technologies

Current limitations and unmet needs

Despite significant advances in bone substitute technology, several fundamental challenges remain unresolved. The biological activity of current materials often falls short of autograft performance, particularly in challenging clinical scenarios [23]. While synthetic materials offer excellent biocompatibility and handling characteristics, they generally lack the complex biological signals that drive robust bone formation [15].

Mechanical properties represent another area where current materials often compromise. The ideal bone substitute should provide immediate structural support while gradually transferring load to newly formed bone. Achieving this balance requires sophisticated engineering that current materials have not fully realized [3].

Cost-effectiveness remains a significant concern for many bone substitute materials. While the direct costs of these products may be justified by avoiding donor site morbidity, the overall economic impact must consider factors such as operative time, hospital stay, and complication rates [12]. Few materials have demonstrated clear cost advantages over autograft when all factors are considered.

Regulatory pathways for bone substitutes vary significantly depending on their classification and intended use. This variability creates challenges for manufacturers and clinicians, as the approval process may not adequately address the unique characteristics of each material. The result is a marketplace with inconsistent standards and un-

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clear comparisons between products [10].

Technological innovations

Three-dimensional printing has emerged as a promising technology for creating customized bone substitutes with precise control over geometry and porosity [21,22,24]. Patient-specific scaffolds can be designed based on imaging data, potentially improving fit and integration. However, the clinical benefits of this customization remain to be demonstrated, and the costs may be prohibitive for routine use [17].

Smart materials that respond to biological signals represent an exciting frontier in bone substitute development. These materials could potentially release growth factors or other therapeutic agents in response to specific cellular or enzymatic signals, providing more precise control over the healing process. However, the complexity of these systems presents significant challenges for clinical translation [9].

Genetic engineering approaches offer the potential to deliver therapeutic genes directly to the graft site, potentially enhancing osteogenesis without the need for expensive protein drugs. However, the safety and efficacy of genetic therapies remain to be established, and regulatory approval is likely to be complex and lengthy [12].

Nanotechnology applications in bone grafting include the development of nanostructured surfaces that may enhance cell adhesion and differentiation. Nanoparticles can also serve as delivery vehicles for drugs or growth factors, potentially improving the efficacy of biologically enhanced materials. However, the long-term safety of nanomaterials in the human body remains a concern [6,25].

Translational challenges

The path from laboratory innovation to clinical application faces numerous obstacles that have slowed the development of next-generation bone substitutes. Regulatory requirements for bone substitutes vary depending on their classification, with some materials requiring extensive clinical trials while others may be approved through less stringent pathways [10]. This variability creates uncertainty for manufacturers and may not adequately ensure patient safety [14].

Clinical trial design for bone substitute evaluation presents unique challenges. Unlike pharmaceutical drugs, bone substitutes are often used in combination with other treatments, making it difficult to isolate their specific effects. The heterogeneity of clinical indications and patient populations further complicates trial design and interpretation [20].

Manufacturing standardization remains a significant challenge for biologically active bone substitutes. The inherent variability in biological materials, combined with complex processing requirements, can lead to batch-to-batch variation that affects clinical performance [13]. Developing quality control methods that ensure consistent biological activity while maintaining cost-effectiveness is an ongoing challenge [4].

Reimbursement policies for bone substitutes vary widely and may not reflect their clinical value. The lack of standardized outcome measures and economic analyses makes it difficult for payers to assess the cost-effectiveness of these materials. This uncertainty can limit patient access to potentially beneficial treatments [23].

Conclusions

The landscape of bone graft substitutes in orthopedic trauma surgery has evolved dramatically over the past several decades, offering surgeons an increasingly sophisticated array of options for managing complex bone defects. While autologous bone grafting remains the gold standard for most applications, the limitations of autograft have driven the development of numerous alternative materials, each with distinct advantages and applications.

The successful use of bone substitutes requires a thorough understanding of their biological properties, mechanical characteristics, and clinical limitations. No single material can replicate all the properties of autograft, and the choice of substitute must be tailored to the specific clinical scenario. The integration of bone substitutes with sound surgical principles, appropriate fixation, and realistic outcome expectations is essential for achieving successful results.

Looking forward, the field continues to evolve with promising developments in biotechnology, materials science, and regenerative medicine. However, the translation of these innovations into clinical practice faces significant challenges related to regulation, cost, and clinical validation. The next generation of bone substitutes will likely combine multiple approaches, potentially including syn-

thetic scaffolds, biological enhancers, and cellular components.

For practicing orthopedic surgeons, staying current with developments in bone substitute technology while maintaining a critical perspective on their clinical value is essential. The decision to use bone substitutes should be based on sound scientific principles, clinical evidence, and patient-specific factors rather than marketing claims or theoretical advantages. When used appropriately, bone substitutes can significantly enhance the surgeon's ability to manage complex bone defects while minimizing patient morbidity.

The future of bone grafting lies not in finding a single perfect substitute for autograft, but in developing a comprehensive understanding of how different materials can be optimally applied to specific clinical scenarios. This nuanced approach, combined with ongoing technological innovation, promises to further improve outcomes for patients with complex bone defects in the years to come.

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Author contribution

Conceptualization: HKS. Data curation: JHC. Project administration: HKS. Writing-original draft: JHC. Writing-review & editing: HKS. All authors read and approved the final manuscript.

Conflict of interests

Hyung Keun Song is a managing 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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Innovative applications of artificial intelligence in orthopedics focusing on fracture and trauma treatment: a narrative review

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Artificial intelligence (AI) is bringing about transformative changes in orthopedic surgery, with its potential being particularly prominent in the field of fracture and trauma treatment. This review explores the current applications and future prospects of AI-driven surgical planning and simulation, robot and image-based navigation surgery, and image-assisted diagnostic technologies. Robotic assistance in orthopedic surgery, which was initially applied to improve accuracy in component implantation for knee and hip arthroplasty and to achieve high precision in spinal screw placement, has recently expanded its use to include accurate, minimally invasive reduction of pelvic fractures. In diagnostics, AI aids in the early prediction and classification of ambiguous fractures in various anatomical regions—for example, detecting shoulder or hip fractures, identifying incomplete atypical femur fractures, and classifying femoral neck fractures—through X-ray image analysis. This improves diagnostic accuracy and reduces medical costs. However, significant challenges remain, including high initial costs, steep learning curves, a lack of long-term studies, data bias, and ethical concerns. Continued research, interdisciplinary collaboration, and policy support are crucial for the widespread adoption of these technologies.

Keywords: Artificial intelligence; Robotics; Wounds and injuries; Orthopedics; Computer-assisted surgery

Review Article

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Introduction

Background

Artificial intelligence (AI) is defined as the application of algorithms that provide machines with the ability to perform tasks traditionally requiring human intelligence, governed by pattern recognition and self-correction on large amounts of data to avoid errors [1]. The orthopedic field is rich with large datasets from digital medical imaging and registries, making it an ideal candidate for extensive AI applications, expanding its potential impact [1].

The influence of AI in orthopedics is already evident in diverse areas such as image recognition, risk prediction, and clinical decision-making [2]. Furthermore, in real surgical practice, conventional surgical methods are heavily reliant on the surgeon's experience and skill, which can lead to variability in outcomes. AI and robotic technologies hold the promise to overcome these limitations, enhancing surgical precision, enabling minimally invasive approaches, and accelerating patient recovery [3].

Looking ahead, the establishment of a fully integrated clinical pathway that lever-

ages AI and robotics in orthopedic trauma is a development we can expect to see implemented in the near future (Fig. 1). This modern workflow, which can be described as 'The integrated pathway of AI and robotics in orthopedic trauma,' will represent a significant leap forward in patient treatment.

Objectives

This review aims to systematically explore the current applications and innovative advancements of AI in orthopedic surgery, with a specific focus on fracture and trauma treatment.

Ethics statement

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

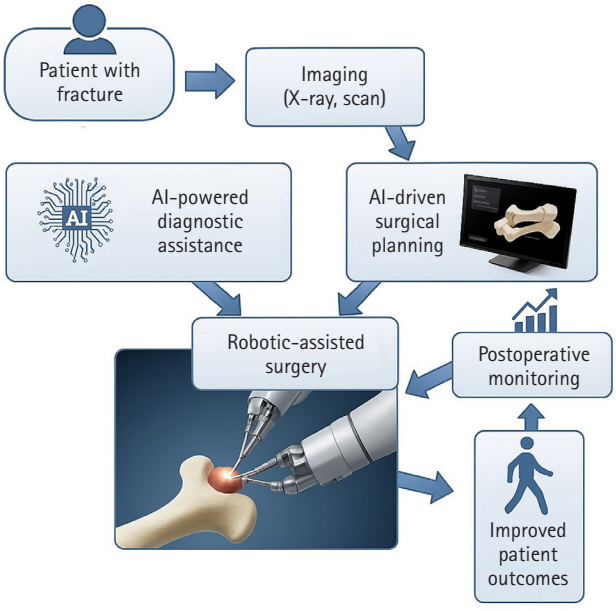

Fig. 1. The integrated pathway of artificial intelligence (AI) and robotics in orthopedic trauma. This flowchart illustrates the modern workflow for treating fractures using artificial intelligence and robotics. The process starts with patient imaging, where AI algorithms assist in the diagnosis and classification of fractures. Next, AI-driven preoperative planning is conducted to determine the optimal surgical approach. During surgery, robotic systems execute the plan with high precision, which ultimately leads to improved patient outcomes, including faster recovery and improved safety.

AI-driven surgical planning and robotic-assisted surgery

The utilization of robots in orthopedic surgery has been trialed since early stages [4], holding the potential for significant improvements in surgical planning, accuracy of component implantation, and patient safety. Robotic-assisted systems aid in enhancing the accuracy of preoperative planning and translating planned surgical steps into intraoperative execution (Fig. 2) [5].

Robotic-assisted hip arthroplasty

In cases of unstable hip fracture, hip arthroplasty is sometimes favored over osteosynthesis. Particularly in elderly patients, those with poor bone quality, or when deformity is present, robotic-assisted hip arthroplasty can be especially beneficial.

In the late 1980s, the ROBODOC system was introduced in the United States. While not strictly a modern machine learning–based AI-assisted robotic system, it contributed to improved femoral component fit and positioning, as well as reduced limb length discrepancy in hip arthroplasty [6,7]. With the progressive development of AI technologies, the Mako robotic-arm assisted surgery system has become a valuable tool in hip surgery. In hip arthroplasty, it is par-

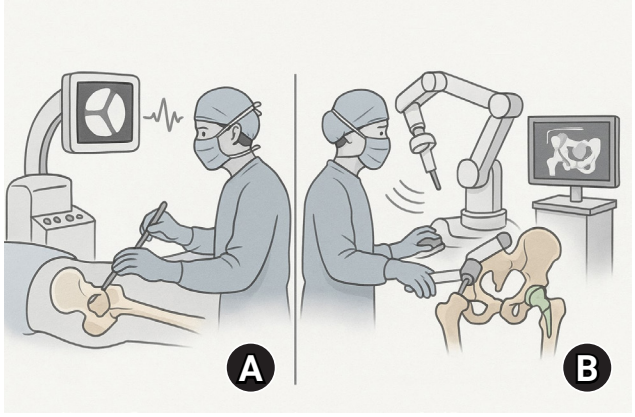

Fig. 2. Precision of robotic-assisted surgery vs. conventional methods. A comparative view of surgical techniques. The conventional method (A) relies on the surgeon's experience and is guided by two-dimensional fluoroscopy, which can have variability. The robotic-assisted method (B) provides haptic feedback to guide the surgeon in executing the plan with high accuracy. This increases the precision of implant placement and fracture reduction while minimizing radiation exposure for the surgical staff.

ticularly helpful for acetabular reaming and cup insertion. The Mako system (Stryker) uses computed tomography (CT) scans to generate patient-specific three-dimensional (3D) models for optimal implant placement planning, and its robotic arm provides haptic feedback to guide precise bone preparation.

When combined with minimally invasive surgery, the Mako system can achieve optimal synergy, allowing direct acetabular reaming to the planned cup size and accurate cup insertion. This enables shorter operative time and smaller incisions while minimizing damage to surrounding tissues.

Robotic-assisted spine surgery

In spine surgery, robots offer essential precision, especially for patients with complex deformities. The SpineAssist robot (Mazor Surgical Technologies) demonstrated remarkable accuracy in pedicle screw placement, with 96% of screws placed within 1 mm of their planned trajectory [8]. Robotic-assisted systems like TiRobot (TINAVI Medical Technologies) provide superior accuracy in percutaneous screw fixation for thoracolumbar fractures compared to manual placement [9]. Robots integrate preoperative and intraoperative imaging data, reducing the need for fluoroscopy and minimizing radiation exposure for both patients and medical staff [10,11]. Robotic guidance overcomes human physiological fatigue, ensuring high operative accuracy, good repeatability, and strong operational stability [12].

Robotic-assisted fracture reduction and trauma surgery

For fracture treatment, particularly complex cases like pelvic fractures, robotic-assisted systems are bringing about significant advancements [13-15]. The intelligent robot-assisted fracture reduction system intelligently designs the optimal reduction path and target position based on preoperative 3D CT scans, and a robotic arm autonomously reduces the affected hemipelvis according to this pre-planned path [13]. This system has enabled accurate and minimally invasive closed reduction for most patients with unstable pelvic fractures, achieving an average residual displacement of 6.65±3.59 mm and an excellent/good reduction rate of 85%. A significant advantage is zero radiation exposure for surgeons during the procedure. The Trauma Pod concept, a semi-automated telerobotic surgical system, also demonstrates future potential for surgical stabilization of critically wounded patients [16]. Robotic assistance has also been investigated for navigating entry points and distal locking bolts in intramedullary nailing [17,18], and for safe robot-assisted identification, dissection, and primary repair of nerves in brachial plexus surgery [19,20].

In addition to pelvic fractures, robot-assisted systems have demonstrated significant clinical benefits in treating intertrochanteric fractures in elderly patients [21,22]. Compared to traditional surgery, robot-assisted proximal femur nail antirotation surgery for unstable femoral intertrochanteric fractures results in a shorter operation time (62.3 minutes vs. 79.5 minutes) [22]. The robot's precise navigation and positioning capabilities reduce the need for repeated manual adjustments and fluoroscopy, leading to a decrease in both intraoperative blood loss (86.8 mL vs. 148.0 mL) and perioperative hidden blood loss (504.7 mL vs. 744.2 mL). This also significantly lowers the rate of allogeneic blood transfusions. The enhanced precision of robot-assisted surgery also translates to faster patient recovery, with patients able to walk independently with crutches sooner (4.0 days vs. 5.2 days) and without crutches in less time (3.9 months vs. 5.1 months) [22]. Postoperative pain relief is quicker, and hip function scores are significantly higher one year after surgery (86.7 points vs. 82.7 points) [21].

Image-based assisted diagnostic technologies

AI is extensively applied in medical image analysis to enhance diagnostic accuracy and support clinical decision-making [23]. In orthopedics, AI is specifically used for fracture identification and classification, as well as nuanced grading of diseases [24-26].

Fracture diagnosis and classification

Early prediction of fractures is crucial for patient prognosis. For incomplete atypical femoral fractures (AFFs), X-ray identification can be challenging, leading to delayed diagnosis and a risk of progression to complete fractures. To address this, an AI model called AFFnet has been developed using a deep convolutional neural network (CNN) to detect and classify AFFs from anteriorposterior radiographs [27]. This model was trained on a dataset including

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incomplete AFFs, complete AFFs, typical femoral fractures, and non-fractured femurs. AFFnet, which uses a novel Box Attention Guide module to direct its focus to key features, showed superior performance to a conventional model (ResNet-50). It achieved a sensitivity of 82% for detecting incomplete AFFs, which was higher than ResNet-50's 56%. This AI-based diagnostic tool has the potential to improve AFF detection, reduce radiologist error, and allow for urgent intervention to improve patient outcomes.

In upper extremity fractures, AI-based fracture detection is one of the most extensively studied and well-developed areas compared to other anatomical regions. In particular, for distal radius fractures, several commercialized AI programs have already been introduced, and their performance is reported to be excellent. Russe et al. [28] reported that the BoneView (Gleamer) program achieved a diagnostic accuracy exceeding 97% and a segmentation accuracy exceeding 94% in real-world clinical data for distal radius fractures. Similarly, in shoulder fractures, a recently developed AI model—an ensemble of Faster R-CNN (ResNet50-FPN, ResNeXt), EfficientDet, and RF-DETR—demonstrated outstanding performance, achieving a diagnostic accuracy of 96% and an F1-score of 0.961 [29].

The Garden classification for femoral neck fractures (FNFs) is a widely used system, but its reliability is a significant drawback [30,31]. To address this, a deep learning model was developed to detect and classify FNFs from plain radiographs [32]. This model, using Faster R-CNN and DenseNet-121, achieved a fracture detection accuracy of 94.1%. It also achieved high area under the curves for different Garden classifications: 0.94 for Garden I/II and 0.99 for Garden III/IV fractures. The model improved the diagnostic accuracy of emergency physicians from 86.3% to 92.0% and significantly enhanced the training outcomes of orthopedic trainees. The model's ability to provide a heatmap visualizing the probable fracture area further aids in diagnosis and physician training. This deep learning algorithm is a promising approach to improve fracture diagnosis and medical education without the costs and radiation of CT scans.

A systematic review of AI and machine learning for hip fracture diagnosis and classification found that AI models demonstrate high accuracy, often exceeding that of human clinicians alone [33]. Across 14 studies [34-47], AI's diagnostic accuracy ranged from 79.3% to 98%, with classification accuracy reaching up to 98.5%. The most common deep learning architectures used were GoogLeNet and DenseNet. While these results are promising, the review concludes that AI should be viewed as a powerful tool to assist and supplement clinical judgment, reducing workload and stress for physicians, rather than a complete replacement. Further research is still needed to validate its effectiveness in real-world clinical settings.

Intraoperative imaging and navigation

Intraoperative 3D imaging plays a crucial role in enhancing surgical accuracy and preventing the need for repeat operations [48]. The use of intraoperative 3D imaging systems like the Iso-C3D (Siemens Medical Solutions) during fracture surgery allows for the analysis of articular fractures and implant positions.

A prospective study on 109 fractures found that intraoperative 3D imaging led to a revision rate of 9.2% for error correction, which may prevent a second operation [49]. This technology is particularly useful for syndesmotic injuries, iliosacral screw fixation, and intraarticula fractures, with revision rates of 23.1%, 8.3%, and 6.6%, respectively, for these fracture sites. The revisions included changing malpositioned implants in six cases, correcting articular reduction in one, and revising syndesmosis malreduction in three. These errors were not visible with conventional 2D fluoroscopy. All surgical staff can exit the operating room during the 62-second 3D scan, which is comparable to the radiation exposure of a standard CT scan or conventional C-arm fluoroscopy, addressing concerns about radiation contamination.

3D intraoperative imaging and navigation are applied in various trauma cases, including acetabular fractures and limb fractures (wrist, rotational femoral malunion, distal tibiofibular syndesmosis, calcaneal fractures) [50-53]. The next frontier in surgical navigation involves integrating robotics, currently being validated for tasks like the reduction of long-bone fractures [54].

Deep learning for osteoporosis screening using X-rays

Researchers are developing deep learning models to predict bone mineral density and fracture risk from conventional X-ray images, such as chest X-rays [55,56]. This approach offers a significant advantage over specialized dual-energy X-ray absorptiometry scans, as X-rays are

more common and less expensive. By using AI to analyze these readily available images, this method could enable opportunistic screening for osteoporosis, leading to earlier detection and intervention for individuals with bone density issues.

Automated sarcopenia assessment using CT scans

Another study focuses on the development and validation of a deep learning-based method for the automated measurement of psoas muscle volume in CT scans [57]. This new AI-driven system dramatically reduces measurement time while providing accurate and consistent results. The automated method is highlighted as a more efficient and reliable tool for diagnosing sarcopenia (age-related muscle loss) and is expected to help establish normal ranges for psoas muscle volume in large populations.

Challenges and future outlook

While AI offers numerous benefits to the orthopedic field, several challenges must be addressed for its widespread clinical adoption [5].

Cost and economic viability

The initial equipment costs for robotic systems can exceed $800,000, with ongoing operational costs also being significant [58]. However, proponents argue that reduced revision rates due to improved accuracy and faster recovery can lead to long-term cost savings [58,59]. Studies suggest that while direct costs of robotic-assisted surgeries are higher, reductions in hospital stay duration and postoperative complications can lead to lower overall healthcare expenditures [60].

Learning curve and operative time

The learning curve associated with new technology requires careful consideration of its impact on training. Initial robotic surgeries may experience longer operative times, and serious complications such as patellar tendon rupture, fracture, or nerve injury have been reported during the early operations of a surgeon's learning curve [9,61]. However, as proficiency increases, surgical efficiency is expected to improve, potentially leading to shorter operative times. Robotic surgery is well-suited for simulation training, which can translate to improved performance in the operating theatre [5].

Long-term studies and generalizability

Current AI research in orthopedics is growing but remains in its early stages, primarily consisting of small, retrospective studies. A lack of long-term, high-impact studies is cited as a limitation restricting the widespread implementation of robotic systems. The diversity of study designs and measurement techniques also makes direct comparisons between studies difficult. To enhance the credibility and generalizability of findings, future research should aim for larger sample sizes, cover a broader range of fracture types, and adopt prospective randomized controlled trial designs and multi-center studies.

Conclusions

AI and robotics have demonstrated immense potential in orthopedics including fracture and trauma treatment, by enhancing surgical precision, reinforcing patient safety, and improving diagnostic accuracy. Advances in preoperative planning and simulation, robotic-assisted surgery, and image-based diagnostic technologies have already yielded significant progress and clinical benefits.

However, widespread adoption faces challenges such as high initial costs, a lack of long-term clinical data, and data bias concerns. To overcome these issues, strong interdisciplinary collaboration and large-scale prospective studies are essential. Successfully integrating these technologies promises to revolutionize the treatment of musculoskeletal conditions and unlock new frontiers in patient care.

Article Information

Author contribution

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

Conflict of interests

Ji Wan Kim is a Deputy Editor of this journal but was not

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Correlation of bone mineral density with ankle fractures in older adults in Korea: a retrospective cohort study

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Background: Bone mineral density (BMD) is well-documented in relation to fractures of the spine, hip, distal radius, and proximal humerus; however, its correlations with other fracture types are less established. This study aimed to analyze BMD and associated risk factors in older adults (≥65 years of age) with osteoporotic ankle fractures. These fractures involve low-energy trauma, resulting from falls from a standing height or lower, and occur from impacts which typically do not cause fractures in individuals with normal bone.

Methods: This retrospective study analyzed data from 1,411 patients diagnosed with ankle fractures admitted to Chosun University Hospital between February 2012 and April 2023. After applying inclusion criteria (age ≥65 years; low energy ankle fracture) and exclusion criteria (high energy trauma, open/multiple fractures, missing dual X-ray absorptiometry [DXA]), 73 of 1,411 patients were analyzed. Lumbar spine, femoral neck, and total hip T scores were obtained with a Horizon Wi DXA scanner, and associations with age, sex, mechanism of injury, comorbidities, smoking status, alcohol consumption, body mass index (BMI), and history of fractures were tested by ANOVA with Scheffe post hoc and Fisher exact tests.

Results: Lower BMD correlated significantly with older age, female sex, and lower BMI ($P<0.05$) in older adults with ankle fractures. No significant associations were observed for comorbidities (diabetes, hypertension, dementia), smoking, alcohol consumption, injury mechanism, or prior fractures.

Conclusion: These results indicate that older age, female, and lower BMI are linked to reduced BMD in ankle fracture patients over 65 years of age. Focused osteoporosis screening and management may therefore be most beneficial for older, low BMI women presenting with ankle fractures.

Level of evidence: IV.

Keywords: Bone density; Ankle fractures; Aged

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Introduction

Background

Osteoporosis is the most common metabolic bone disease in old age, and with the rapid increase in the elderly population, understanding and preventing the related factors is important. A previous history of osteoporotic fractures is a significant predictor of new fractures, making early and accurate diagnosis of osteoporotic fractures crucial [1].

Currently, bone mineral density (BMD) is primarily measured in the spine and hip, and a lower BMD value indicates a higher risk of fractures in the spine and hip [2]. Low BMD is a well established risk factor for osteoporotic fractures of the spine, hip (including femoral neck and intertrochanteric fractures), distal radius, and proximal humerus, however, its correlation with other fracture types is less established [3,4]. In particular, while the incidence of ankle fractures increases in postmenopausal women [5,6], some studies suggest that ankle fractures may have a weaker association with osteoporosis [7]. This has led to ongoing research [8] to further investigate the relationship.

Objectives

This study aims to analyze BMD and its associated risk factors in elderly patients (65 years and older) with osteoporotic ankle fractures. These fractures typically result from low-energy trauma, such as falls from a standing height or lower, which generally do not cause fractures in individuals with normal bone [9]. Various factors are known to influence BMD, including age, sex, physical activity level, smoking, alcohol consumption, and body weight [10]. Indeed, several studies have shown that higher body weight is correlated with higher BMD and may lower the incidence of hip fractures [10,11]. Building on these findings, the present study examines whether these factors also play a role in ankle fractures among the elderly and seeks to clarify the relationship between low BMD and the ankle fractures in this population.

Methods

Ethics statement

It was approved by the institutional review board (IRB) of the Chosun University Hospital (IRB No. 2024-10-025).

Study design

It is a retrospective cohort study based on the electronic medical records of the hospital.

Setting

From February 2012 to April 2023, a total of 1,411 patients were admitted to Chosun University Hospital with ankle fractures. Their electronic medical records were analyzed.

Participants

The inclusion criteria for this study were: age ≥65 years, a single ankle fracture sustained from low-energy trauma (e.g., a fall from standing height or lower), and availability of BMD data. Therefore, we excluded 430 patients who had open fractures, multiple fractures, or experienced high-energy trauma (e.g., a fall from a height >1.5 m or traffic accidents). Among the remaining patients, 87 met the age criterion (≥65 years), but 14 had not undergone BMD testing. Consequently, a total of 73 patients were included in the final analysis.

Variables

Primary outcome variables were BMD of the lumbar spine, femoral neck, and total hip. Predictor/explanatory variables were age, sex, injury mechanism, comorbidities, lifestyle factors (smoking, alcohol drinking), BMI, and fracture history.

Data sources/measurement

BMD was measured at lumbar spine, femoral neck, and total hip using a Horizon Wi dual-energy X-ray absorptiometry (DXA) scanner (Hologic Inc., USA), following the manufacturer's recommended protocols.

Patients were categorized by age into three groups: ≤69 years (group a), 70–79 years (group b), and ≥80 years (group c). The mechanism of injury was classified into low-energy injuries corresponding to osteoporotic fractures, such as twisting injury, slip down, falls from a standing height or less, or other types of injuries. Comorbidities were classified based on the presence of diabetes, hypertension, and dementia, which are highly prevalent in the elderly. BMD was categorized according to World Health Organization criteria, with T scores defined as normal (>–1.0), osteopenia (–1.0 to –2.5), and osteoporosis (≤ –2.5). Smoking status was divided into smokers and non-smokers, while alcohol consumption was classified as drinking if the intake was 3 units or more per day (with one unit representing 8–10 grams of alcohol, roughly equivalent to a standard glass of beer (285 mL), a single measure of spirits (30 mL), a medium-sized glass of wine (120 mL), or 1 measure of an aperitif (60 mL) and non-drinking otherwise. Body mass index (BMI) was classified according to Korea standards into normal weight (18.5–22.9), overweight (23–24.9), obesity (25–29.9), and severe obesity (≥30.0). Lastly, patients were

categorized based on a history of previous fractures.

Bias

Potential confounders such as medication use (e.g., corticosteroids, osteoporosis treatment), nutritional status, vitamin D levels, physical activity, and socioeconomic status were not controlled for. Their omission may impact associations between BMD and the studied risk factors. Sex distribution (61.6% women) may confound observed associations between age and BMD.

Study size

All included subjects were analyzed; therefore, no sample size calculation was performed.

Statistical methods

Data were analyzed using IBM SPSS ver. 27.0 (IBM Corp.). Descriptive statistics were used to analyze general characteristics and fracture-related risk factors of the study subjects. To identify differences in BMD across these characteristics, ANOVA was performed. Post-hoc analysis was conducted using the Scheffe test, and Fisher exact test was used for cells with frequencies less than 5.

Results

A total of 73 patients (mean age, 71.6±5.8 years) were included, of whom 28 (38.4%) were male and 45 (61.6%) were female. Most ankle fractures resulted from low-energy mechanisms such as twisting injuries (38.4%) or slip-down events (54.8%), and nearly half the patients (53.4%) had osteoporosis based on BMD T-scores. Detailed demographic and clinical characteristics, including comorbidities, smoking/alcohol status, and BMI categories, are presented in Table 1.

Table 1. Demographics of the patients (n=73)

Variable	Value
Age (yr)	71.64±5.74
≤69	31 (42.5)
70–79	33 (45.2)
≥80	9 (12.3)
Sex (male:female)	28 (38.4):45 (61.6)
Injury mechanism	
Twisting injury	28 (38.4)
Slip down	40 (54.8)
Fall down	3 (4.1)
Other	2 (2.7)
Comorbidity (no:yes)	
Diabetes	46 (63):27 (37)
Hypertension	35 (47.9):38 (52.1)
Dementia	72 (98.6):1 (1.4)
Bone mineral density	
Normal	7 (9.7)
Osteopenia	27 (37)
Osteoporosis	39 (53.4)
Health behavior (no:yes)	
Smoking	67 (91.8):6 (8.2)
Alcohol	69 (94.5):4 (5.5)
Body mass index (kg/m^2)	24.89±3.16
Normal	21 (28.8)
Overweight	17 (23.3)
Obese	31 (42.5)
Severely obese	4 (5.5)
Previous fracture history (no:yes)	59 (80.8):14 (19.2)

Values are presented as mean±standard deviation or number (%).

The mean BMD of the total patients was –2.40±1.00. Specifically, –1.96±1.41 for the spine T-score, –1.80±0.99 for the hip-neck T-score, and –1.19±0.95 for the total hip T-score. The study revealed a statistically significant difference in mean BMD among the age groups (P=0.023), with post-hoc testing indicating a significant difference between the group a (≤69 years) and group b (70–79 years). Regarding spine T-score, ANOVA analysis also showed a difference among the groups (P=0.030), and post-hoc testing confirmed a significant difference between the group a (≤69 years) and group b (70–79 years). Group a (≤69 years) and group c (≥80 years) did not reach statistical significance in post-hoc test. This may be due to the small sample size in the group c, which can limit statistical power and obscure true differences. Hip neck T-score and total hip T-score also differed across age (P=0.014 and P=0.009, respectively). By sex, the mean BMD was –2.09±0.92 in males and –2.58±1.01 in females, indicating a statistically significant difference (P=0.040), and both spine and total hip T-scores also showed differences (P=0.038 and P=0.024, respectively). In BMI classification, the mean BMD was –2.91±0.97 in the normal-weight group, –1.92±1.21 in the overweight group, –2.35±0.75 in the obese group, and –2.13±0.96 in the severely obese group. ANOVA analysis revealed a statistically significant difference among these groups (P=0.017), with post-hoc testing indicating a significant difference be-

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tween the normal-weight and overweight groups. Also, the total hip T-score showed a difference among these groups (P=0.039). In injury mechanisms, comorbidities, smoking status, alcohol consumption and previous fracture history groups, none of these differences were statistically significant. In the case of dementia, only one patient (n=1) in our study had this condition, rendering any statistical comparison or interpretation of BMD differences in that subgroup highly limited. Therefore, we opted to include this variable for completeness but acknowledge that no meaningful conclusions can be drawn from such a small sample (Table 2).

Discussion

Key results

Our study demonstrated that older age, females, and lower BMI were significantly associated with lower BMD in elderly patients with ankle fractures, whereas comorbidities (including diabetes, hypertension, dementia), smoking, alcohol consumption, injury mechanism, and previous fracture history did not show a notable impact.

Interpretation/comparison with previous studies

Although our study did not directly measure peripheral BMD at the ankle joint, a previous study [12] analyzed the correlation between central BMD (spine and hip) and peripheral BMD (medial cartilage, distal tibia, lateral cartilage, and talus) using DXA, reporting a significant association across all measurement sites. Such findings imply that assessing BMD at or around the ankle may be useful for identifying high-risk patients. While our analysis focused on central BMD, these prior results suggest a potential linkage between central and peripheral bone measurements that warrants further direct evaluation in future studies.

Many studies indicate that higher body weight can provide a protective effect on bone through appropriate mechanical loading [13]. Also, a recent systematic review and meta-analysis found that obesity is generally associated with higher areal BMD, yet the overall fracture risk pattern is heterogeneous, weight bearing sites may benefit from greater mechanical loading, whereas non weight bearing or peripheral sites can still experience increased fracture risk [14]. Our study suggests that lower BMI in elderly patients with ankle fractures was associated with lower BMD. However, obesity has been reported to have a negative impact on BMD due to systemic inflammatory responses, which may be harmful to bones. Furthermore, increased bone marrow adipogenesis in obese individuals may contribute to reduced bone mass [13]. A recent study suggested that the relationship between body weight and BMD follows an inverted U-shaped pattern [15]. In this study, lower BMD was observed in underweight individuals, with BMD increasing up to a certain threshold, beyond which excessive obesity was associated with a decline in BMD. This pattern may help explain the complex relationship between BMD and body weight. Therefore, in our study, classification based solely on body weight likely led to the inclusion of a majority of older and female patients in the low BMI group, which consequently exhibited lower BMD. Although some ankle fracture studies have linked high BMI to fracture risk [16,17], our study focuses on BMD rather than fracture incidence, suggesting that BMI may modulate bone quality differently from its effect on fall mechanics. These findings highlight the complexity of the relationship between ankle fractures and BMD, which cannot be explained by a single factor. Given the ongoing debates and investigations in this area, further studies are needed to clarify these associations.

One might intuitively assume that patients with diabetes would exhibit lower BMD due to impaired bone metabolism. However, recent studies suggest that individuals with type 2 diabetes often have normal or even slightly higher BMD compared to non-diabetic controls, despite an overall increased risk of fractures [18,19]. This apparent paradox has been attributed to factors such as the accumulation of advanced glycation end-products, alterations in bone microarchitecture, and the potential confounding effect of higher BMI in many patients with type 2 diabetes [20]. In other words, even when BMD measurements appear preserved or elevated, qualitative changes in bone tissue and a heightened propensity for falls may collectively raise fracture risk. Our finding of relatively higher BMD among diabetic patients aligns with these reports, underscoring the need to interpret BMD values in the context of broader clinical and metabolic factors.

Limitation

A key limitation of this study is its retrospective design at a single institution, coupled with a relatively small sample

Table 2. Associations between bone mineral density (BMD) and patients' characteristics (n=73)

Variable		Category	BMD			Spine T-score			Hip neck T-score			Total hip T-score		
			Mean±SD	t/F	P-value	Mean±SD	t/F	P-value	Mean±SD	t/F	P-value	Mean±SD	t/F	P-value
Total			−2.40±1.00			−1.96±1.41			−1.80±0.99			−1.19±0.95		
Age (yr)		≤69[a]	−2.09±0.84	3.967	0.023 (a>b)	−1.62±1.24	3.697	0.03 (a>b)	−1.55±0.98	4.508	0.014 (a>c)	−0.92±0.93	5.015	0.009 (a>c)
		70–79[b]	−2.56±1.08			−2.36±1.29			−1.82±1.00			−1.26±0.95		
		≥80[c]	−2.87±0.97			−1.66±2.08			−2.58±0.45			−1.87±0.71		
Sex		Male	−2.09±0.92	2.088	0.040	−1.53±1.51	2.117	0.038	−1.59±0.98	1.474	0.145	−0.87±1.00	2.299	0.024
		Female	−2.58±1.01			−2.23±1.30			−1.93±0.98			−1.38±0.88		
Injury mechanism		Twisting injury	−2.38±0.80	2.003	0.122	−2.12±1.25	1.871	0.143	−1.63±0.96	1.279	0.288	−1.04±0.85	0.980	0.407
		Slip down	−2.28±1.06			−1.69±1.44			−1.82±1.02			−1.22±1.02		
		Fall down	−3.40±0.56			−3.37±0.60			−2.53±0.32			−1.80±0.30		
		Other	−3.45±2.19			−2.80±3.11			−2.60±0.99			−1.85±1.63		
Comorbidity	Diabetes	No	−2.55±1.02	1.793	0.077	−2.13±1.53	1.343	0.184	−1.84±1.04	0.317	0.752	−1.25±1.01	0.675	0.502
		Yes	−2.13±0.93			−1.67±1.16			−1.75±0.90			−1.09±0.86		
	Hypertension	No	−2.37±1.11	0.176	0.861	−2.11±1.35	0.883	0.380	−1.63±1.14	1.384	0.171	−1.03±1.09	1.376	0.173
		Yes	−2.42±0.90			−1.82±1.48			−1.95±0.81			−1.33±0.79		
	Dementia	No	−2.39±1.01	0.204	0.839	−1.95±1.42	0.383	0.703	−1.79±0.99	0.814	0.419	−1.19±0.96	0.013	0.99
		Yes	−2.60±0.00			−2.50±0.00			−2.60±0.00			−1.20±0.00		
Health behavior	Smoking	No	−2.40±1.01	0.243	0.808	−1.20±1.44	0.104	0.918	−1.83±0.99	0.731	0.467	−1.21±0.96	0.634	0.528
		Yes	−2.30±0.92			−2.02±1.25			−1.52±0.93			−0.95±0.88		
	Alcohol	No	−2.42±1.00	0.968	0.336	−1.99±1.43	0.921	0.360	−1.83±0.99	0.989	0.326	−1.21±0.97	0.834	0.407
		Yes	−1.93±0.92			−1.33±0.75			−1.33±0.75			−0.80±0.54		
Body mass index		Normal (a)	−2.91±0.97	3.621	0.017 (a<b)	−2.50±1.54	2.498	0.067	−2.25±0.87	2.441	0.072	−1.66±0.76	2.932	0.039
		Overweight (b)	−1.92±1.21			−1.48±1.44			−1.56±1.22			−1.05±1.14		
		Obese (c)	−2.35±0.75			−1.98±1.01			−1.69±0.88			−1.02±0.90		
		Severely obese (d)	−2.13±0.96			−0.93±2.47			−1.28±0.69			−0.58±0.62		
Previous fracture history		No	−2.37±0.97	0.431	0.668	−1.95±1.43	0.141	0.888	−1.77±0.99	0.599	0.551	−1.14±0.97	0.957	0.342
		Yes	−2.50±1.14			−2.01±1.38			−1.94±0.99			−1.41±0.86		

The BMD value presented corresponds to the lowest T-score among the measured sites. F value for analysis of variance among three or more groups.
Post-hoc analysis using Scheffe test revealed statistically significant differences (P<0.05).
SD, standard deviation; t/F, test statistic (t value for two group comparisons).

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size, which may restrict the generalizability of our findings. The small sample size also likely contributed to some unexpected observations. For example, although BMD T-scores decreased with advancing age, this trend might be confounded by the higher proportion of female patients in the oldest group. Postmenopausal women typically show a steeper decline in bone mass, suggesting that the observed age-related decrease may partly reflect sex differences rather than aging alone. Additionally, our data revealed that non-smokers and non-drinkers had slightly lower BMD contrary to most established reports [21,22]. Such discrepancies are likely influenced by limited statistical power and potential confounders like medication use, lifestyle factors and other unmeasured variables.

Suggestion for further studies

Future studies should therefore involve larger, more diverse populations and incorporate detailed individual factors to clarify these trends and strengthen the understanding of the relationship between BMD and ankle fractures.

Conclusion

In conclusion, lower BMD in elderly patients (≥65 years) with low energy ankle fractures is associated with older age, female sex, and lower BMI. These findings highlight the importance of assessing BMD and osteoporosis assessment, particularly in ankle fracture patients who have these characteristics.

Article Information

Author contribution

Conceptualization: SHL, CHL, JYL. Data curation: SHL, CHL, SJP. Funding: JYL. Formal analysis: SHL, JYL. Methodology: SHL, SJP, JYL. Project administration: JYL. Investigation: SHL, CHL. Supervision: JYL, SJP. Writing-original draft: SHL, CHL, SJP, JYL. Writing-review & editing: SHL, CHL, SJP, JYL. All authors read and approved the final manuscript.

Conflict of interests

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

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Data availability

Contact the corresponding author for data availability.

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Supplementary materials

None.

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Risk factors for ankle fractures in older adults based on clinical components of the Fracture Risk Assessment (FRAX) tool and comorbidities in Korea: a retrospective case-control study

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Background: Ankle fractures are common in older adults; however, their relationship with osteoporotic fractures remains unclear. This study aimed to evaluate potential risk factors for ankle fractures in older adults by analyzing individual clinical components of the Fracture Risk Assessment (FRAX) tool and comorbidities.

Methods: We conducted a retrospective case-control study including 84 patients aged ≥65 years with ankle fractures and 150 controls who underwent bone mineral density (BMD) testing without prior ankle fractures. The variables analyzed included age, sex, body mass index, smoking, alcohol consumption, prior fracture history, and comorbidities such as hypertension, diabetes mellitus, and dementia. BMD was measured at the spine, total hip, and femoral neck.

Results: Univariate analysis showed that alcohol consumption, diabetes mellitus, and total hip T-score categories were significantly associated with ankle fractures. In binary logistic regression, alcohol consumption remained significantly associated with higher ankle fracture risk (odds ratio [OR], 5.302; 95% confidence interval [CI], 1.778–15.811; P=0.003), and both osteopenia and osteoporosis at the total hip were also associated with increased risk (OR, 3.260, P=0.049; OR, 3.561, P=0.031, respectively). Diabetes mellitus did not reach statistical significance in the adjusted model (P=0.074). Model fit was adequate (Hosmer-Lemeshow P=0.377), and post hoc power analysis confirmed sufficient sample size.

Conclusions: These findings suggest that lower total hip BMD and alcohol-related factors may be associated with ankle fracture risk in older adults. The FRAX score itself was not calculated; instead, this study focused on analyzing selected clinical components. Limitations include the retrospective design, lack of fall and medication data, and cross-sectional BMD assessment.

Level of evidence: III.

Keywords: Ankle fractures; Aged; Comorbidity; Risk factors

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Introduction

Background

Ankle fractures are increasing in incidence due to aging, increased sports activities, industrial accidents, and traffic accidents, making them one of the most common fractures encountered in orthopedic practice [1]. In particular, among elderly individuals aged ≥65 years, ankle fractures occur not only due to high-energy trauma (e.g.,

traffic accidents, falls) but also from low-energy injuries, such as tripping during ambulation [2]. In Finland, which has experienced aging earlier than Korea, the number of ankle fractures in individuals aged 60 years and older increased from 369 cases in 1970 to 1,545 cases in 2000, representing an approximately 319% increase. If this trend continues, it is projected that the incidence of ankle fractures in this population will triple by 2030 [3]. Consequently, evaluating the risk of ankle fractures and establishing prevention strategies have become critical issues. To assess fracture risk, the World Health Organization (WHO) introduced the Fracture Risk Assessment (FRAX) tool, which estimates the 10-year probability of major osteoporotic fractures in individuals aged 40–90 years. The FRAX score considers various clinical factors, including age, sex, body mass index (BMI), previous fractures, bone mineral density (BMD), smoking, alcohol consumption, and underlying diseases. It incorporates epidemiological data from different countries to predict fracture risk, playing a crucial role in osteoporosis prevention and treatment decisions [4].

However, it remains unclear whether ankle fractures occur via the same mechanism as osteoporotic fractures [5]. Osteoporotic fractures typically result from diminished bone mass and structural integrity, often occurring following minimal trauma. These fragility fractures are most commonly observed in the vertebrae, hip, distal radius, and proximal humerus, where the link to low BMD is well established. In contrast, the association between ankle fractures and decreased BMD remains controversial. For example, Stein et al. [6] found no significant difference in BMD between postmenopausal women with and without ankle fractures. Similarly, Therdyothin et al. [7] and Seeley et al. [8] found no meaningful correlation between BMD and ankle fractures in elderly reviews. However, Biver et al. [9] reported lower BMD and altered trabecular structure in women with ankle fractures. Lee et al. [10] also found that elderly patients with ankle fractures had reduced bone attenuation and more complex fracture patterns. These findings suggest that ankle fractures in the elderly may share features with osteoporotic fractures.

Objectives

Based on this perspective, we aimed to investigate the potential risk factors for ankle fractures in older adults by analyzing the individual components of the FRAX tool. However, due to the retrospective nature of our study and the presence of follow-up loss, we focused on selected FRAX clinical components and comorbidities, rather than the total FRAX score, to assess their potential relevance to ankle fracture risk.

Methods

Ethics statement

This study was approved by the Institutional Review Board (IRB) of Chosun University hospital (IRB No. 2024-10-024). Obtainment of informed consent was waived due to the retrospective use of de-identified medical records.

Study design

It is a retrospective case-control study. It was described according to the STROBE statement (https://www.strobe-statement.org/).

Setting

It was conducted at Chosun University Hospital and Chonnam University Hospital in Gwangju, Korea, from 2020 to 2022.

Participants

The case group included 84 patients aged 65 years and older who were diagnosed with an ankle fracture using simple radiographs and computed tomography (CT). The control group comprised 150 patients aged ≥65 years with no history of ankle fractures who underwent BMD testing during their hospital visit. Patients were excluded if they had high-energy trauma, multiple fractures, or prior surgeries affecting dual-energy X-ray absorptiometry (DXA) reliability (Fig. 1). Among the initial participants, eight patients with multiple trauma and five patients with high-energy injuries were excluded from the case group. In the control group, nine patients were excluded due to inaccurate DXA measurements related to prior orthopedic surgeries.

Variables

The primary outcome variable is the presence of ankle fracture. The primary predictive variables included age, sex, BMI, previous fracture history, BMD, smoking, alcohol consumption, and underlying diseases (hypertension, diabetes mellitus [type 2 diabetes mellitus in all cases], and

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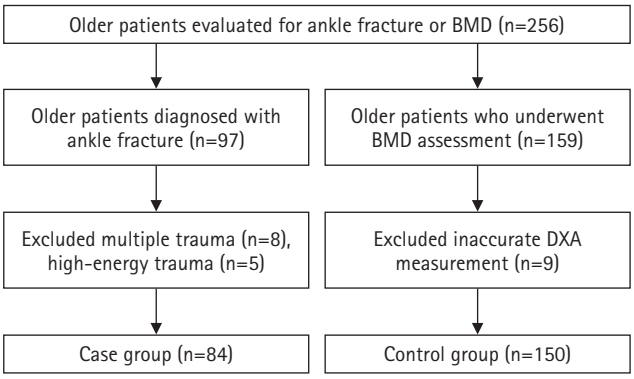

Fig. 1. Flowchart depicting the participant selection process for inclusion in the study. Participants were selected from two hospitals between January 2020 and December 2022, with exclusion criteria applied based on age, data completeness, and eligibility for bone mineral density testing. BMD, bone mineral density; DXA, dual-energy X-ray absorptiometry.

dementia). Explanatory variables were BMD at spine, hip neck, total hip.

Data sources/measurement

Data were extracted from the electronic medical records, including X-ray absorptiometry findings. Ankle fractures can be classified based on anatomical location and injury mechanism, which are important for determining treatment strategies. However, our primary goal was to identify relevant risk factors in elderly patients; therefore, detailed classification was not included in the present analysis.

BMD was measured at the spine, total hip, and femoral neck, with the lowest T-score used for osteoporosis status. Each site was analyzed independently to determine site-specific associations (Tables 1, 2). Hypertension, diabetes mellitus, and dementia were classified based on documented prior diagnoses in the medical records.

Prior osteoporosis treatment history and BMD trends were unavailable due to the retrospective design, representing a limitation. We did not compute the FRAX score but analyzed selected FRAX-related clinical variables along with comorbidities such as diabetes mellitus, hypertension, and dementia for exploratory variables.

Sex was classified as male or female; age was grouped as 65–69, 70–79, or ≥80 years. Smoking and alcohol consumption were defined per WHO FRAX criteria. Alcohol intake ≥3 units/day was considered drinking; less was non-drinking. Due to limitations in medical records, alcohol intake

Table 1. Demographics of participants (n=234)

Variable	Value
Sex	
Male	79 (33.8)
Female	155 (66.2)
Age (yr)	72.32±5.79
≤69	89 (38.0)
70–79	114 (48.7)
≥80	31 (13.2)
Underlying diseases (negative:positive)	
Diabetes mellitus	177 (75.6):57 (24.4)
Hypertension	112 (47.9):122 (52.1)
Dementia	229 (97.9):5 (2.1)
Health behaviors (absent:present)	
Smoking	215 (91.9):19 (8.1)
Alcohol consumption	200 (85.5):34 (14.5)
Body mass index (kg/m^2)	24.93±3.27
Underweight (<18.5)	4 (1.7)
Normal weight (18.5–22.9)	59 (25.2)
Overweight (23.0–24.9)	62 (26.5)
Obesity (25.0–29.9)	94 (40.2)
Severe obesity (≥30.0)	15 (6.4)
Previous fracture history	
Absent	202 (86.3)
Present	32 (13.7)

Values are presented as number (%) or mean±standard deviation.

Table 2. Bone mineral density characteristics of participants

Variable	Value
Bone mineral density	−2.28±1.03
Normal	24 (10.3)
Osteopenia	104 (44.4)
Osteoporosis	106 (45.3)
Spine T score	−1.75±1.46
Normal	63 (26.9)
Osteopenia	92 (39.3)
Osteoporosis	79 (33.8)
Hip neck T score	−1.84±0.95
Normal	39 (16.7)
Osteopenia	131 (56.0)
Osteoporosis	64 (27.4)
Total hip T score	−1.22±0.96
Normal	91 (38.9)
Osteopenia	121 (51.7)
Osteoporosis	22 (9.4)

Bone mineral density distribution of participants according to measurement site. Values are presented as number (%) or mean±standard deviation. T-scores were classified into normal, osteopenia, and osteoporosis based on the World Health Organization criteria.

was categorized as binary variables, which may not reflect true exposure levels or severity.

BMI was categorized using Korean Society for the Study of Obesity criteria. BMD was classified per WHO criteria: normal (T>–1.0), osteopenia (–1.0 to –2.5), and osteoporosis (T≤–2.5). Previous fracture history was included.

Fall history and functional status were not available from records and could not be included, a key limitation.

Bias

Selection bias was minimized by applying strict inclusion and exclusion criteria and enrolling consecutive patients from two tertiary hospitals. Information bias was reduced through standardized DXA protocols and verification of comorbidity diagnoses using electronic medical records. However, due to the retrospective design, unmeasured confounding factors such as fall history, medication use, and functional status may have influenced the results

Study size

No a priori sample size calculation was performed because of the retrospective design. Instead, a post hoc power analysis was conducted using the logistic regression module in G*Power.

For diabetes mellitus, the following parameters were applied: two-tailed test, odds ratio of 0.559, baseline risk of 0.322 (57/177), significance level of 0.05, total sample size of 234, R^2 other X with X of 0.10, binary distribution, and X parameter π of 0.243 (57/234). Under these conditions, the achieved statistical power was 0.318.

For alcohol consumption, the analysis used a two-tailed test, odds ratio of 5.302, baseline risk of 0.400 (80/200), significance level of 0.05, total sample size of 234, R^2 other X with X of 0.10, binary distribution, and X parameter π of 0.145 (34/234). The achieved statistical power in this model was 0.970.

For Total Hip T-score, two separate post hoc power analyses were performed for osteopenia and osteoporosis compared with normal bone density. For osteopenia versus normal, the analysis used a two-tailed test, odds ratio of 3.260, baseline risk of 0.400 (60/150), significance level of 0.05, total sample size of 234, R^2 other X with X of 0.10, binary distribution, and X parameter π of 0.517 (121/234). Under these conditions, the achieved statistical power was 0.752. For osteoporosis versus normal, the analysis used a two-tailed test, odds ratio of 3.561, baseline risk of 0.240 (19/79), significance level of 0.05, total sample size of 234, R^2 other X with X of 0.10, binary distribution, and X parameter π of 0.094 (22/234). The achieved statistical power in this model was 0.662.

Statistical methods

This study did not employ case-control matching based on age, sex, or BMI due to a limited sample size (n=234). Instead, logistic regression analysis was used to adjust for these variables statistically. Analyses were performed using IBM SPSS ver. 27.0 (IBM Corp.). The chi-square test was used for group comparisons; Fisher exact test was applied when appropriate. Variables with P<0.1 in univariate analysis were included in the logistic regression model and results with P<0.05 were considered statistically significant. Model fit was assessed using the Hosmer-Lemeshow test (P=0.377), indicating adequate calibration.

Results

Baseline characteristics

A total of 234 participants were included in the final analysis, consisting of 84 patients in the ankle fracture group and 150 in the control group. Tables 1 and 2 each summarizes baseline characteristics and BMD characteristics. There were no significant differences between groups in age, sex, or BMI category.

Univariate analysis

Univariate analysis (Table 2) revealed no significant associations between ankle fracture occurrence and sex (P=0.447), age (P=0.676), BMI (P=0.538), hypertension (P=0.742), dementia (P=0.590), smoking (P=0.682), or prior fracture history (P=0.164).

However, diabetes mellitus was significantly associated with ankle fracture occurrence (P=0.038). Alcohol consumption also showed a significant association (P=0.001) (Table 3). In terms of BMD, there were no significant differences in overall mean BMD, spine T-score, or hip neck T-score. However, total hip T-score categories were significantly associated with fracture incidence (P=0.040), with a higher frequency of osteoporosis in the fracture group (Table 4).

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Table 3. Presence of ankle fractures according to participants' characteristics

Category	With ankle fracture	Without ankle fracture	χ^2 or t	P-value
Sex			0.579	0.447
Male	31 (36.9)	48 (32.0)		
Female	53 (63.1)	102 (68.0)		
Age (yr)	71.64±5.67	72.71±5.84	1.350	0.178
≤69	35 (41.7)	54 (36.0)	0.783	0.676
70–79	28 (45.2)	76 (50.7)		
≥80	11 (13.1)	20 (13.3)		
Underlying diseases				
Diabetes mellitus			4.309	0.038
Negative	57 (67.9)	120 (80.0)		
Positive	27 (32.1)	30 (20.0)		
Hypertension			0.108	0.742
Negative	39 (46.4)	73 (48.7)		
Positive	45 (53.6)	77 (51.3)		
Dementia			0.037	0.590
Negative	82 (97.6)	147 (98.0)		
Positive	2 (2.4)	3 (2.0)		
Health behavior				
Smoking			0.168	0.682
Absent	78 (92.9)	137 (91.3)		
Present	6 (7.1)	13 (8.7)		
Alcohol consumption			10.068	0.001
Absent	80 (95.2)	120 (80.0)		
Present	4 (4.8)	30 (20.0)		
Body mass index (kg/m^2)	24.87±3.22	24.97±3.31	0.228	0.820
Underweight (<18.5)	0	4 (2.7)	3.117	0.538
Normal weight (18.5–22.9)	23 (27.4)	36 (24.0)		
Overweight (23.0–24.9)	22 (26.2)	40 (26.7)		
Obesity (25.0–29.9)	35 (41.7)	59 (39.3)		
Severe obesity (≥30.0)	4 (4.8)	11 (7.3)		
Previous fracture history			1.941	0.164
Absent	69 (82.1)	133 (88.7)		
Present	15 (17.9)	17 (11.3)		

Comparison of demographic and clinical characteristics between participants with and without ankle fractures. Values are presented as number (%) or mean±standard deviation. The Fisher exact test was used when expected cell counts were less than 5.

Logistic regression analysis

Binary logistic regression analysis was performed including variables with P<0.1 from the univariate analysis (Table 5). Alcohol consumption remained a significant independent risk factor for ankle fracture, with non-drinkers as the reference group (OR, 5.302; 95% CI, 1.778–15.811; P=0.003).

Total hip osteopenia (T-score between –1.0 and –2.5) and osteoporosis (T-score≤–2.5) were independently associated with increased fracture risk compared to individuals with normal BMD (T-score>–1.0), the reference group. The odds ratio for osteopenia was 3.260 (95% CI, 1.003–10.598; P=0.049) and for osteoporosis was 3.561 (95% CI, 1.127–11.255; P=0.031).

The association with diabetes mellitus did not reach statistical significance (OR, 0.559; 95% CI, 0.295–1.058; P=0.074), with individuals without diabetes mellitus as the reference group. Although this result suggests a lower risk of ankle fracture in the diabetes group, the finding should be interpreted with caution given the borderline P-value.

Table 4. Presence of ankle fractures according to participants' BMD

Variable	With ankle fracture	Without ankle fracture	χ^2 or t	P-value
BMD	−2.34±0.99	−2.23±1.05	0.810	0.419
Normal	9 (10.7)	15 (10.0)	3.154	0.207
Osteopenia	31 (36.9)	73 (48.7)		
Osteoporosis	44 (52.4)	62 (41.3)		
Spine T score	−1.90±1.41	−1.66±1.49	1.205	0.229
Normal	19 (22.6)	44 (29.3)	3.76	0.153
Osteopenia	30 (35.7)	62 (41.3)		
Osteoporosis	35 (41.7)	44 (29.3)		
Hip neck T score	−1.79±0.95	−1.87±0.95	0.619	0.537
Normal	19 (22.6)	20 (13.3)	4.062	0.131
Osteopenia	41 (48.8)	90 (60.0)		
Osteoporosis	24 (28.6)	40 (26.7)		
Total hip T score	−1.16±0.94	−1.26±0.99	0.721	0.471
Normal	31 (36.9)	60 (40.0)	6.418	0.040
Osteopenia	50 (59.5)	71 (47.3)		
Osteoporosis	3 (3.6)	19 (12.7)		

Distribution of ankle fractures according to bone mineral density (BMD) status by measurement site. Values are presented as mean±standard deviation or number (%). Statistical analysis was performed using the chi-square test or the Fisher exact test when appropriate.

Table 5. Logistic regression for ankle fracture risk (n=234)

Variable	Category	B	SE	P-value	OR	95% CI
Underlying diseases	Diabetes mellitus (vs. negative)	−0.582	0.326	0.074	0.559	0.295–1.058
Health behavior	Alcohol consumption (vs. non-drinker)	1.688	0.557	0.003	5.302	1.778–15.811
Total hip T score	Normal	-	-	0.095	-	-
	Osteopenia (vs. normal)	1.182	0.601	0.049	3.260	1.003–10.598
	Osteoporosis (vs. normal)	1.270	0.587	0.031	3.561	1.127–11.255

Results of logistic regression analysis identifying independent factors associated with ankle fractures. Odds ratios (ORs) and 95% confidence intervals (CIs) are shown. Reference groups: diabetes-negative, non-drinkers, and participants with normal total hip T-score. A P-value of <0.05 was considered statistically significant. Model fit was confirmed using the Hosmer-Lemeshow test (P=0.377).

Model evaluation

Model fit was assessed using the Hosmer-Lemeshow goodness-of-fit test, which showed no evidence of poor fit (P=0.377), indicating that the model adequately described the data. Additionally, based on power analysis (OR, 1.9; α, 0.05; power, 0.95), a minimum of 171 participants was required. With 234 subjects included, the study achieved an actual power of 0.95, confirming sufficient statistical power.

Discussion

Key results

Among 234 older adults (84 cases, 150 controls), logistic regression identified alcohol consumption and reduced total hip BMD as independent risk factors for ankle fractures. Alcohol use increased fracture risk more than fivefold (OR, 5.302; 95% confidence interval [CI], 1.778–15.811; P=0.003). Both osteopenia (OR, 3.260; P=0.049) and osteoporosis (OR, 3.561; P=0.031) at the total hip were significantly associated with ankle fractures, whereas diabetes mellitus showed only borderline significance (P=0.074).

Interpretation/comparison with previous studies

Moayeri et al. [11] conducted a meta-analysis of 30 studies and found increased fracture risk in patients with type 2 diabetes mellitus, though not at the ankle. Wang et al. [12] later found a significant association between diabetes and ankle fractures. However, few studies have specifically examined this relationship in elderly individuals, supporting its inclusion here.

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Du et al. [13] demonstrated that hypertension was associated with increased future fracture risk, and Li et al. [14] confirmed a higher risk of osteoporotic fractures in hypertensive individuals. Still, limited research exists on ankle fractures specifically, particularly in the elderly.

Dementia was included due to its known link to fall risk. Dumurgier and Tzourio [15] found dementia to be the most prevalent neurological condition in older adults. Phelan et al. [16] and Simpkins et al. [17] both showed that fall incidence increases in individuals with Alzheimer's disease, the most prevalent type of dementia. Liu et al. [18] reported that over three-quarters of ankle fractures in the elderly resulted from low-energy trauma, highlighting the relevance of fall-related conditions. Based on these considerations, hypertension, diabetes mellitus, and dementia were included as variables in this study.

Interestingly, while several components such as age, sex, BMI, prior fractures, and BMD variables other than total hip T-score were not consistently associated with ankle fracture occurrence, certain findings, including alcohol consumption, total hip T-score, and diabetes mellitus status, were found to be associated with ankle fractures in the elderly, but should be interpreted with caution.

In our study, alcohol consumption was significantly associated with an increased risk of ankle fractures. Specifically, individuals who reported alcohol consumption had a 5.302-fold higher risk of ankle fractures compared to non-drinkers (OR, 5.302; 95% CI, 1.778–15.811; P=0.003). This finding is consistent with previous research investigating alcohol-related injuries to the foot and ankle. Pirruccio and Farber [19] reported that alcohol use is mechanistically linked to traumatic foot and ankle fractures through increased incidence of falls, particularly in emergency department visits across the United States. Alcohol consumption has been repeatedly associated with increased fall risk in older adults, primarily due to its effects on sensorium, balance, and concentration, which are further exacerbated by age-related physiological decline [19]. In a nationwide longitudinal study by Wang et al. [20], the authors reported that the pattern of association between alcohol consumption and fracture risk varies depending on the anatomical site. Specifically, vertebral fractures demonstrated a J-shaped association with alcohol intake. Mild to moderate drinking was associated with reduced risk, while excessive intake increased the risk. In contrast, limb fractures, including ankle fractures, showed a dose-dependent linear increase in fracture risk with increasing alcohol consumption. Taken together, our findings suggest that alcohol consumption may contribute to an increased risk of ankle fractures, potentially through mechanisms involving fall susceptibility and alcohol-induced alterations in neuromuscular coordination or bone integrity. However, due to the observational nature of the study and the presence of multiple confounding factors—including physical frailty, comorbidities, and lifestyle behaviors, alcohol consumption should be interpreted with caution and may not be considered an independent risk factor with certainty. Further prospective studies with more precise measurement of alcohol exposure are needed to clarify this relationship.

Next, both osteopenia and osteoporosis, as defined by total hip T-score, were significantly associated with an increased risk of ankle fractures compared to individuals with normal total hip T-score group. Specifically, the risk of ankle fracture was 3.26 times higher in the osteopenia group (OR, 3.260; 95% CI, 1.003–10.598) and 3.56 times higher in the osteoporosis group (OR, 3.561; 95% CI, 1.127–11.255). Cummings and Melton [21] reported that, in addition to the presence of low BMD itself, the anatomical site of BMD measurement may influence its predictive value for fracture risk. In particular, BMD at the proximal femur provides better predictive accuracy for overall fracture risk than spinal measurements, likely due to fewer degenerative artifacts and greater measurement reliability at the hip.

A cohort study by Leslie et al. [22] further explored this issue by examining the clinical implications of discordance between total hip and femoral neck T-scores. They suggested that the total hip T-score may better reflect susceptibility to osteoporotic fractures compared to the femoral neck. For example, individuals whose total hip T-score was at least one unit lower than their femoral neck T-score had significantly higher risks of major osteoporotic fractures.

They proposed that although hip sites are highly correlated, there are different proportions of cortical and trabecular bone, which may contribute differently to bone strength across the skeleton. Furthermore, femoral neck is more prone to measurement artifacts due to osteoarthritic changes such as medial buttressing, especially in older individuals. In our study, total hip T-score–based

classifications of osteopenia and osteoporosis were both independently associated with increased ankle fracture risk, suggesting that lower total hip BMD may contribute to susceptibility to ankle fractures. Nevertheless, this interpretation must be approached with caution. In a recent systematic review and meta-analysis, So et al. [23] reported that elderly patients with ankle fractures had significantly lower femoral neck BMD compared to those without fractures. However, this relationship remains controversial and is not yet fully established [7]. Also, due to the retrospective design of our study and lack of information, we were unable to account for potential confounding factors such as prior use of osteoporosis medications, adherence to treatment, or longitudinal changes in BMD over time. Additionally, Shevroja et al. [24] argued that DXA-derived T-scores do not account for other important aspects of bone health, such as microarchitecture, bone turnover, or mineralization. They further noted that unmeasured factors, including fall history, balance, muscle strength, and physical function, may also play a significant role in fracture occurrence [24]. Therefore, while our findings suggest that total hip T-score is a potentially valuable indicator of ankle fracture risk in the elderly. Although earlier studies have reported no association between total hip T score and ankle fractures, our findings suggest that total hip T-score may still provide valuable predictive information. However, further prospective studies incorporating treatment history, bone quality parameters, and functional risk factors are warranted to validate this association.

Next, diabetes mellitus variant was associated with a lower risk of ankle fracture, although the association did not reach statistical significance (P=0.074). This finding contrasts with prior studies, which have consistently reported diabetes mellitus as a risk factor for fractures, attributed to factors such as impaired bone quality, microvascular complications, neuropathy, and increased fall risk [25]. Given that the observed inverse association may be influenced by unmeasured or residual confounders, and considering that the P-value falls below the conventional threshold of 0.10 but not 0.05, this variable should not be disregarded. According to statistical recommendations, variables with P-values below 0.10 in univariate analyses are often retained in multivariable models to control for potential confounding. Therefore, the inverse association observed in our study may not reflect a true protective effect, but rather a result of confounding or sample-specific variation such as treatment confounding and healthy user bias.

Limitations

We were unable to assess fall history, functional status, or osteoporosis treatment adherence, which are important confounders in fracture risk assessment.

Conclusions

In conclusion, our findings suggest that certain FRAX score components—such as alcohol consumption—may contribute to ankle fracture risk. Moreover, unlike the conventional FRAX model, which is based solely on the femoral neck T-score, our results indicate that the total hip T-score may also have meaningful relevance in assessing this risk. Notably, the current FRAX tool estimates the 10-year probability of major osteoporotic fractures based on a composite risk score incorporating clinical variables and femoral neck BMD. Several FRAX components—including prior glucocorticoid use and secondary osteoporosis—could not be assessed in our study. Future prospective studies incorporating longitudinal BMD data, treatment history, and functional risk factors are warranted to confirm these findings and facilitate the development of an ankle fracture–specific risk prediction model.

Article Information

Author contribution

Conceptualization: MJS, JYL. Data curation: MJS, SWJ, SJP. Formal analysis: SWJ, JYL. Methodology: SWJ, SJP. Project administration: JYL. Funding: JYL. Investigation: MJS. Supervision: JYL. Writing-original draft: MJS,SJP. Writing-review & editing: MJS, SWJ, JYL. All authors read and approved the final manuscript.

Conflict of interests

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

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Data availability
Contact the corresponding author for data availability.

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Supplementary materials
None.

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Comparative results of the femoral neck system versus the dynamic hip screw for stable femoral neck fractures in older adults in Korea: a retrospective cohort study

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Background: This study aimed to compare the clinical and radiological outcomes of the femoral neck system (FNS) and the dynamic hip screw (DHS) for the internal fixation of stable femoral neck fractures in older adults.

Methods: This retrospective cohort study included 48 matched older adult patients based on sex, age, BMI, and osteoporosis status, who had undergone internal fixation with either FNS or DHS for stable femoral neck fractures between January 2010 and December 2022. To minimize selection bias, a 1:1 case-control matching was performed based on sex, age, body mass index (BMI), and the presence of osteoporosis. A total of 48 patients (24 in each group) were included. We compared perioperative data (operation time, hemoglobin change, transfusion rate), functional outcomes using the Koval score, and radiological outcomes, including union rate, femoral neck shortening, and complication rates.

Results: The mean operation time was significantly shorter in the FNS group than in the DHS group (60.9 minutes vs. 70.8 minutes; P=0.007). There were no statistically significant differences between the two groups in the union rate (87.5% in FNS vs. 95.8% in DHS), femoral neck shortening, final Koval score distribution, or overall complication rates (12.5% in both groups).

Conclusions: For treating stable femoral neck fractures in older adults, the FNS demonstrated comparable clinical and radiological outcomes to the DHS, with the distinct advantage of a shorter operation time. While these findings suggest that the FNS is a promising and safe alternative that may reduce the surgical burden, definitive conclusions are precluded by the small sample size, warranting further research to corroborate these results.

Level of evidence: IV.

Keywords: Femoral neck fractures; Femur neck; Bone screws; Internal fracture fixation; Aged

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Introduction

Background

With the global trend of an aging society, the incidence of osteoporotic hip fractures, particularly femoral neck fractures, continues to rise steadily [1]. A femoral neck fracture is considered a severe injury associated with high morbidity and mortality, as it not only causes extreme pain and immediate loss of ambulation, rendering patients

unable to maintain an independent daily life, but also leads to fatal systemic complications such as pressure sores, pneumonia, and deep vein thrombosis due to prolonged bed rest. Therefore, a core principle of modern orthopedic treatment is to perform prompt and stable surgical fixation, taking into account the patient's overall medical condition, in order to prevent the vicious cycle of complications and facilitate early functional recovery.

The treatment strategy for femoral neck fractures is determined based on multiple factors, including the patient's age, preinjury activity level, and the degree of fracture displacement and stability, with options ranging from internal fixation to arthroplasty. Among these, internal fixation, or osteosynthesis, is preferentially considered for relatively young or active patients, as well as for non-displaced or stable fractures, as it allows for the preservation of the native joint, thereby maintaining proprioception and physiological function. To date, multiple cannulated screws (CCS) and the dynamic hip screw (DHS) have been widely used as standard methods for the internal fixation of stable femoral neck fractures. The DHS, in particular, is a proven treatment that can provide strong dynamic compression at the fracture site, and its reliability in achieving high union rates in the elderly population with stable fractures has been well-documented, establishing it as a benchmark for osteosynthesis [2]. However, the DHS has the distinct disadvantage of requiring a relatively large skin incision and extensive soft-tissue dissection, which can increase intraoperative blood loss and consequently impose a significant surgical burden on elderly patients with multiple medical comorbidities [3,4].

To overcome these shortcomings and maximize the benefits of minimally invasive surgery, the femoral neck system (FNS; DePuy Synthes) was recently developed. The FNS is a fixation device that combines a locking compression bolt with an angularly stable locking plate, designed to provide excellent rotational and angular stability despite using a single bolt [5]. This structural feature allows for surgery through a significantly smaller incision compared to the DHS, which is expected to offer the biological advantage of preserving the soft tissues and blood supply to the femoral head. Numerous biomechanical studies have demonstrated that the FNS provides mechanical stability comparable to or superior to existing fixation devices [6-8]. Initial clinical studies have reported that the FNS is associated with shorter operation times and less blood loss, while achieving satisfactory union rates [5,9,10].

However, most of the existing research has focused on comparing the FNS with CCS [11-13], and there is still a lack of studies directly comparing the clinical outcomes of the FNS with those of the DHS, the traditional gold standard, in elderly patients with osteoporotic fractures [3,4].

Objectives

This study aimed to directly compare the perioperative data, as well as the clinical and radiological outcomes, of internal fixation using the FNS versus the DHS in elderly patients with stable femoral neck fractures, and thereby to investigate the clinical utility and safety of the FNS in a real-world clinical setting.

Methods

Ethics statement

The study's protocol was reviewed and approved by the Institutional Review Board (IRB) of Keimyung University Dongsan Hospital (IRB No. 2025-08-001), and informed consent was waived due to the study's retrospective nature.

Study design

It is a retrospective cohort study, employing a case-control matching design to compare outcomes of two surgical methods. It was described according to the STROBE statement (https://www.strobe-statement.org/).

Setting

This study was conducted at Keimyung University Dongsan Hospital. The study period extended from January 2010 to December 2022, during which all eligible consecutive patients with stable femoral neck fractures were treated according to institutional protocols. All surgical procedures were performed by a single, experienced orthopedic surgeon with a consistent technique. Patients were positioned supine on a fracture table, and closed reduction of the fracture was performed under C-arm fluoroscopic guidance. For the FNS group, an approximately 3–4 cm skin incision was made over the lateral aspect of the greater trochanter, and the FNS was inserted according to the manufacturer's guidelines. For the DHS group, a standard lateral approach was used with an approximately 8–10 cm incision to insert

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the DHS. A 1-hole side plate was used for all patients in the FNS group. In the DHS group, a 2-hole plate was utilized in 21 cases and a 3-hole plate in three cases. Furthermore, an additional anti-rotation screw was employed in eight cases within the DHS group to augment rotational stability. Efforts were made to achieve an ideal implant position in the center of the femoral head on both anteroposterior and lateral views. However, in some cases, a slightly inferior position of the bolt in the anteroposterior view was unavoidable due to individual variations in fracture patterns or femoral neck anatomy. According to the manufacturer's guidelines, the tip of the screw or bolt was intended to be positioned within 5–10 mm of the subchondral bone. Postoperatively, all patients received prophylactic antibiotics for 48 hours. Mechanical and pharmacological prophylaxis, including low-molecular-weight heparin and intermittent pneumatic compression devices, was implemented to prevent deep vein thrombosis. A standardized rehabilitation protocol was applied to all patients in both the FNS and DHS groups. The protocol was uniformly structured to promote early mobilization as follows: sitting as tolerated from the day of surgery to mitigate the risks of pulmonary complications. This was followed by mobilization to a wheelchair on postoperative days 1 to 2. Subsequently, the initiation of tolerable standing and toe-touch weight-bearing with a walker was permitted from postoperative day 3 for all patients. Demographic, clinical, and radiological data were collected through a review of electronic medical records and the picture archiving and communication system.

Participants

This study included patients aged 65 years or older who were diagnosed with a stable femoral neck fracture and underwent internal fixation with either the FNS or the DHS.

A stable fracture was defined as a Garden type I or II. To ensure comparability between the groups and to minimize selection bias, a 1:1 case-control study design was employed. Patients in the FNS group were matched with patients in the DHS group based on sex, age (within ±3 years), body mass index (BMI; within ±2 kg/m^2), and the presence of osteoporosis, as confirmed by a dual-energy X-ray absorptiometry (DEXA) scan (Fig. 1). Ultimately, a total of 48 patients, with 24 in each group, were included in this study. All patients included in the study were female. The mean age was 74.5 years (range, 66–85 years) in the FNS group and 75.0 years (range, 67–86 years) in the DHS group. The mean BMI was 21.7 kg/m^2 and 22.4 kg/m^2, respectively, and the mean T-score on DEXA scan was –3.5 and –3.4, respectively. No statistically significant differences were observed between the two groups in any of the demographic characteristics, including age, BMI, and bone mineral density (Table 1).

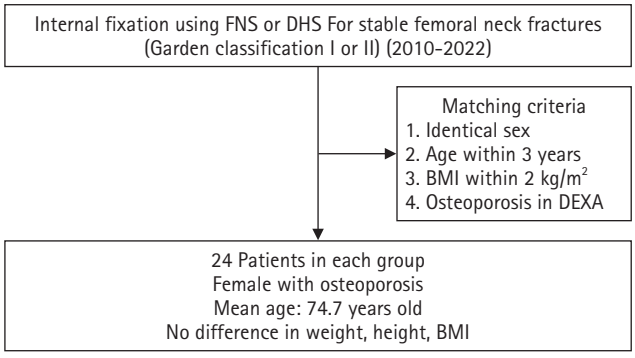

Fig. 1. A flow chart of patient selection. FNS, femoral neck system; DHS, dynamic hip screw; BMI, body mass index; DEXA, dual-energy X-ray absorptiometry.

Table 1. Demographics of the two groups

Variable	FNS group (n=24)	DHS group (n=24)	P-value
Sex (male:female)	0:24	0:24	1.000
Mean age (yr)	74.5	75.0	0.673
Average body mass index (kg/m^2)	21.7	22.4	0.336
Average preoperative hemoglobin level (g/dL)	11.7	11.2	0.302
Average postoperative days 2 hemoglobin level (g/dL)	11.1	10.6	0.243
Average T-score on DEXA (femoral neck area)	–3.5	–3.4	0.573
Fracture classification (Garden classification I:II)	2:22	4:20	0.388
Average follow-up interval (mo)	14.9	30.9	0.003

FNS, femoral neck system; DHS, dynamic hip screw; DEXA, dual-energy X-ray absorptiometry.

Variables

Primary outcomes included radiographic union, femoral neck shortening, and complication rates (fixation failure, avascular necrosis [AVN], and nonunion). Secondary outcomes included perioperative variables (operation time, hemoglobin change, transfusion rate) and functional outcomes assessed with the Koval score.

Data sources/measurement

Clinical assessment

Perioperative variables included the total operation time (from anesthesia induction to skin closure), the change in hemoglobin level between preoperative and postoperative days 2 (Table 1), and the incidence of allogenic blood transfusion during hospitalization (until postoperative days 3). Functional assessment was performed using the Koval score [14] to evaluate ambulatory capacity before the injury and at the final follow-up. The Koval score ranges from 1 (independent ambulation) to 5 (bedridden), with higher scores indicating greater functional dependence.

Radiological assessment

Standardized anteroposterior and lateral radiographs of the hip were obtained immediately postoperation and at each follow-up visit (6 weeks, 3 months, 6 months, 1 year, and annually thereafter). Radiological union was defined as the disappearance of the fracture line, accompanied by the absence of pain on full weight-bearing. Femoral neck shortening was calculated as the difference in the distance from the center of the femoral head to the lateral cortex of the femur between the immediate postoperative and final follow-up radiographs (Fig. 2). Femoral neck shortening was measured independently by two experienced orthopedic surgeons, and the average of their values was used for the analysis. Complications, including fixation failure (e.g., screw cut-out or excessive sliding), AVN of the femoral head, nonunion, and the need for revision surgery, were investigated.

Bias

Measurement bias was reduced by independent, blinded radiographic assessments. All consecutive eligible patients with complete records were included to minimize attrition bias.

Study size

No sample size estimation was performed; all available matched cases during the study period were analyzed.

Statistical methods

All statistical analyses were performed using IBM SPSS ver. 26.0 (IBM Corp.). Continuous variables between the two groups were compared using the Mann-Whitney U test after assessing for normality. In contrast, categorical variables were analyzed using Fisher exact test or the lin-

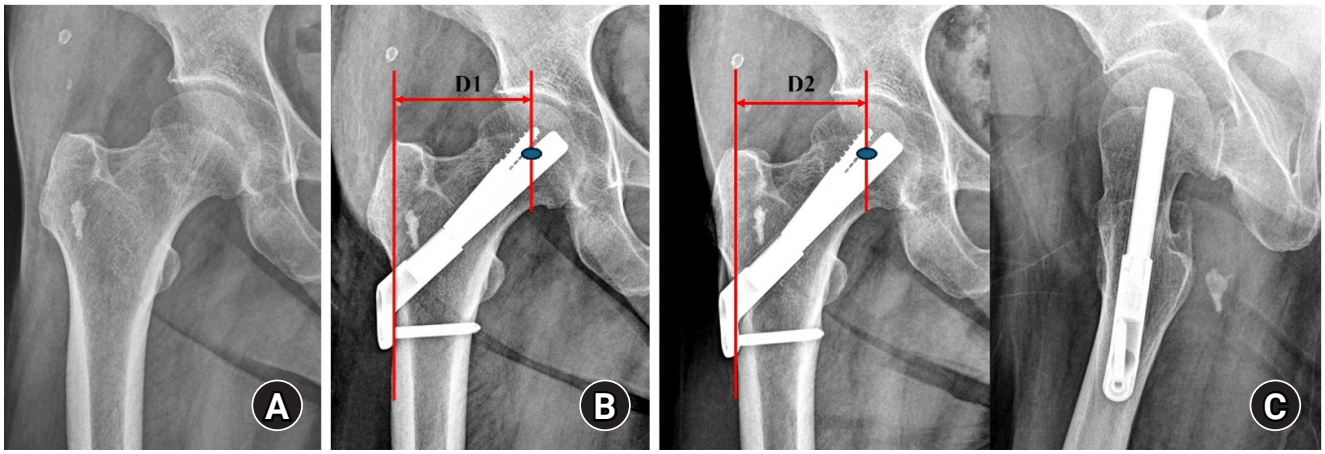

Fig. 2. (A, B) A 67-year-old female patient with a right femoral neck fracture (Garden type 1) treated with the femoral neck system. (C) The postoperative 4-year radiograph shows a well-healed fracture site and no complications related to the implant. Femoral neck shortening (D2–D1) was calculated as the difference in the distance from the center of the femoral head to the lateral cortex of the femur between the immediate postoperative and final follow-up radiographs.

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ear-by-linear association test. The Wilcoxon signed-rank test was used to compare preinjury and final follow-up Koval scores. A P-value of less than 0.05 was considered statistically significant for all analyses.

Results

Clinical outcomes

The mean operation time was significantly shorter in the FNS group, at 60.9 minutes, compared to 70.8 minutes in the DHS group (P=0.007). The postoperative decrease in hemoglobin levels (1.0 g/dL in the FNS group vs. 1.2 g/dL in the DHS group; P=0.311) and the transfusion rate (16.7% [4/24] in the FNS group vs. 25.0% [6/24] in the DHS group; P=0.477) showed a tendency to be lower in the FNS group. However, this difference did not reach statistical significance.

There was no difference in the preinjury Koval scores between the two groups. At the final follow-up, the Koval scores in both groups showed a significant decline in function compared to their preinjury status (P<0.001). However, there was no statistically significant difference in the distribution of final follow-up Koval scores between the two groups (P=0.071) (Table 2).

Radiological outcomes

At the final follow-up, the union rate was 87.5% (21/24) in the FNS group and 95.8% (23/24) in the DHS group, with no statistically significant difference between the two groups (P=0.296) (Figs. 2, 3). The mean femoral neck shortening was measured at 6.1 mm in the FNS group and 5.9 mm in the DHS group, and no significant difference was observed (P=0.427).

Complications occurred in a total of three cases (12.5%)

Table 2. Clinical results of the two groups

Variable	FNS group (n=24)	DHS group (n=24)	P-value
Preinjury Koval score[a] (1/2/3/4/5 grade)	12/8/3/1/0	12/8/3/1/0	1.000
Final follow-up Koval score[a] (1/2/3/4/5 grade)	6/5/2/10/1	6/12/2/4/0	0.071
Average hemoglobin drop (between preoperative and postoperative days 2; g/dL)	1.0	1.2	0.311
Transfusion rate (until postoperative days 3)	4/24	6/24	0.477
Mean operation time (min)	60.9	70.8	0.007

FNS, femoral neck system; DHS, dynamic hip screw.
[a]Number of patients in each Koval grade.

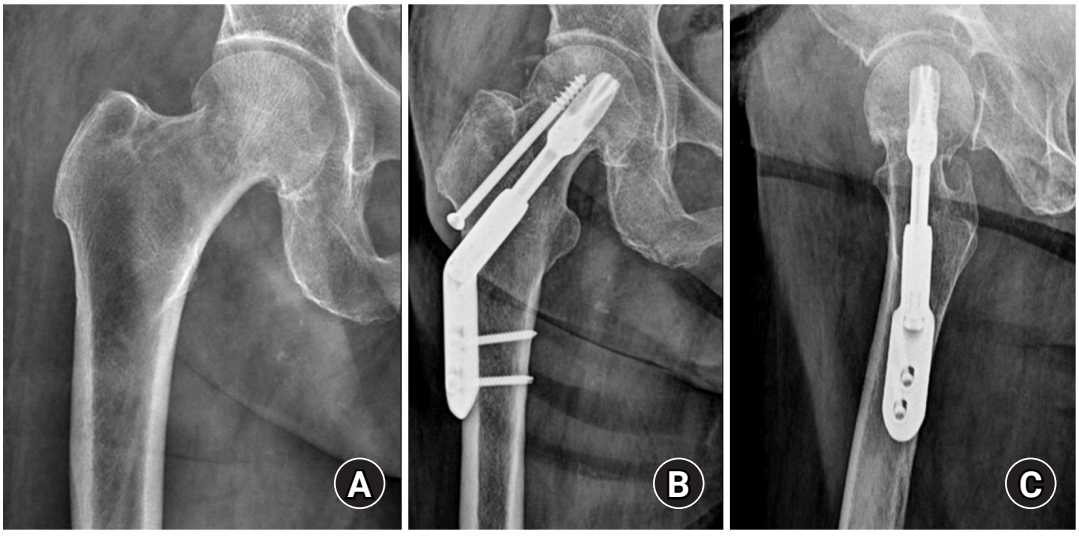

Fig. 3. (A, B) An 86-year-old female patient with a stable right femoral neck fracture treated with a dynamic hip system. (C) Postoperative 1-year anteroposterior and axial radiographs show a well-healed fracture site and no complications related to the implant.

in the FNS group, which included two cases of fixation failure and one case of AVN. In the DHS group, complications also occurred in three cases (12.5%), consisting of one case of nonunion and two cases of AVN. There was no significant difference in the overall complication rate between the two groups (P=1.000). All patients who experienced complications (six patients) required conversion to arthroplasty (Table 3, Fig. 4).

Discussion

Key results

The principal finding of this investigation was a statistically significant reduction in mean operative duration of approximately 10 minutes in the FNS group compared to the DHS group (60.9 minutes vs. 70.8 minutes; P=0.007). This result provides objective evidence of the minimally invasive advantage of the FNS and is congruent with the findings of several antecedent studies.

Interpretation/comparison with previous studies

Niemann et al. [3] reported that the FNS significantly reduced not only the operation time but also the fluoroscopy time compared to the DHS. Similarly, a study by Zheng et al. [4] identified that the FNS had the shortest operative duration when compared to both DHS and CCS. For elderly patients, particularly those burdened by multiple medical comorbidities, a reduction in operative duration has significant clinical implications that extend beyond mere surgical efficiency. It is directly correlated with reduced exposure to anesthetic agents, diminished potential for intraoperative hemorrhage, and a lower risk of surgical site infection secondary to abbreviated exposure of the surgical field to the external environment, all of which may positively influence the patient's systemic physiological condition [15]. In the current study, although not reaching statistical significance, a trend toward a more minor postoperative hemoglobin decrement and a lower transfusion rate was observed in the FNS group, a finding likely attrib-

Table 3. Radiologic results of the two groups

Variable	FNS group (n=24)	DHS group (n=24)	P-value
Union rate (%)	21 (87.5)	23 (95.8)	0.296
Femoral neck shortening (mm)	6.1	5.9	0.427
Complication			1.000
Fixation failure	2	0	
Avascular necrosis	1	2	
Nonunion	0	1	

FNS, femoral neck system; DHS, dynamic hip screw.

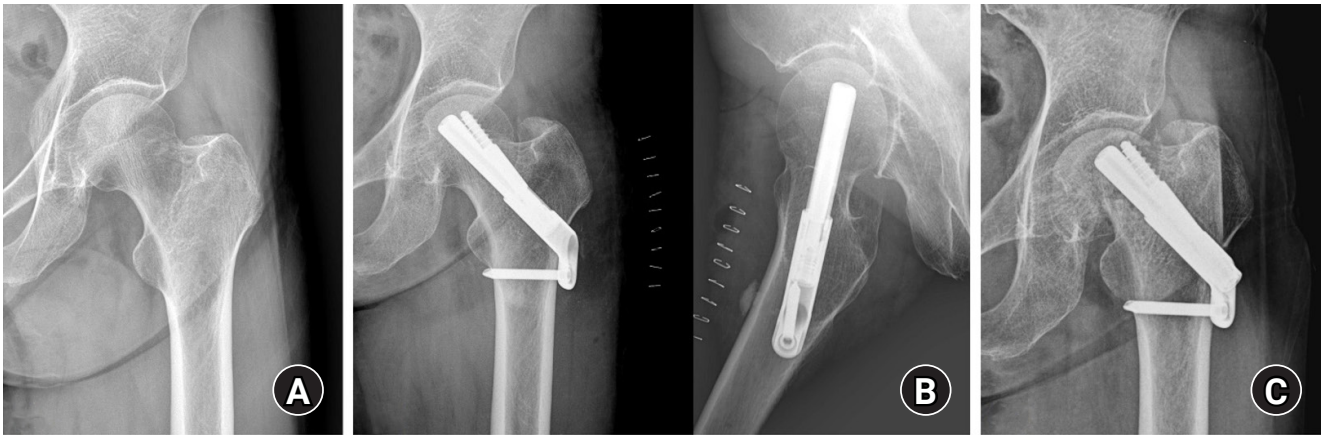

Fig. 4. (A) A 64-year-old female patient sustained a stable femoral neck fracture on the left side. (B) The fracture was treated with the femoral neck system (FNS; anteroposterior and axial view). (C) A postoperative 6-month radiograph shows fixation failure of the FNS.

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utable to the smaller cutaneous incision and less extensive soft-tissue dissection required for the FNS procedure. It may, therefore, be posited that the FNS constitutes a valid therapeutic alternative capable of mitigating the physiological burden of surgery in this vulnerable patient demographic.

In this study, no significant differences were found between the two groups for most clinical and radiological outcomes, except for the operation time. The union rate, functional outcome at final follow-up (Koval score), and the degree of femoral neck shortening were all comparable. Although the union rate in the DHS group was slightly higher (95.8% vs. 87.5%), this difference was not statistically significant, which may be attributed to the limited sample size of our study. Nevertheless, both fixation methods demonstrated high rates of successful union, suggesting clinical comparability in this regard. This clinical equivalence is supported by experimental evidence demonstrating the sufficient biomechanical stability provided by the FNS. A biomechanical study by Moon et al. [8] on a basicervical femoral neck fracture model, there were no statistically significant differences in axial stiffness and rotational stability between FNS and DHS. This implies that the combination of a locking compression bolt and an angularly stable plate in the FNS can maintain fracture stability as effectively as the lag screw and side plate construct of the DHS. It is therefore conceivable that, in stable fractures, the combination of 'adequate stability' and the biological advantages of 'soft-tissue and blood-supply preservation' offered by FNS contributed to achieving clinical outcomes comparable to those provided by robust fixation with DHS.

The complication rate was also identical in both groups at 12.5%, which is within an acceptable range compared to other large-scale studies. Davidson et al. [10] reported a reoperation rate of 15.7% in their analysis of 102 FNS patients, and Stassen et al. [5] reported a mechanical failure rate of 9.3% in a one-year follow-up study. The two cases of fixation failure in our FNS group may be related to the poor bone quality of the osteoporotic elderly patients or surgical technique, rather than to an inherent problem with the implant itself. Several biomechanical studies have emphasized that the stability of the FNS is highly dependent on the precise central placement of the implant within the femoral neck [7,16]. Especially in elderly patients with low bone mineral density, accurate implant positioning is crucial to prevent fixation failure, particularly the 'cut-out' phenomenon. Furthermore, Cha et al. [17] have pointed out that the 5-mm increments in the FNS bolt length can make fine adjustments of the insertion depth difficult and have proposed a surgical technique to compensate for this. Therefore, a thorough understanding of and attention to these technical aspects are required to achieve successful clinical outcomes with the FNS.

Femoral neck shortening is a primary concern after internal fixation, as it can lead to limb length discrepancy, abductor muscle weakness, and an abnormal gait, ultimately resulting in functional impairment. In our study, the mean femoral neck shortening was minimal and did not differ significantly between the two groups (6.1 mm in the FNS group vs. 5.9 mm in the DHS group). While this suggests both implants effectively control for excessive collapse, it is important to note that even minor shortening can have clinical implications for abductor function and gait. The lack of a statistically significant difference in our cohort should be interpreted with caution, and larger studies are needed to definitively compare the two implants in their ability to prevent clinically relevant shortening. While some studies have reported that FNS is more effective than CCS in preventing femoral neck shortening [11,12], the results tend to be similar when compared with DHS, as observed in our study. This may be because both devices operate on a similar mechanism that allows for dynamic compression at the fracture site while controlling for excessive vertical displacement.

Limitations

First, due to its retrospective design, there is a potential for selection bias. Although we attempted to minimize this by employing a case-control matching design to ensure similar demographic characteristics between the groups, the fundamental limitation of non-randomization and the potential for unmeasured confounding variables remain. Second, the study was conducted at a single institution with a relatively small number of patients. This limited sample size inherently restricts the statistical power of our analyses, making it difficult to detect subtle but potentially clinically meaningful differences between the groups. Consequently, outcomes that did not reach statistical significance, such as the trends observed in union rates and transfusion rates, should be interpreted with caution as

they may be susceptible to a type II error. Additionally, the small sample size precluded a sub-group analysis based on the radiographic position of the implant. While the surgical goal was optional center-center placement, minor variations (some inferior placement on anteroposterior position view) due to fracture patterns or patient anatomy were unavoidable. The potential influences of these deviations on fixation stability and clinical results could not be statistically assessed and therefore represent another limitation of our study. Third, the follow-up period was relatively short and different between the two groups, which is insufficient to fully assess long-term complications such as AVN or posttraumatic arthritis. Fourth, our analysis of blood-related outcomes did not account for potential confounding variables such as the time from injury to admission and the time from admission to surgery. These intervals could have influenced preoperative hemoglobin levels and transfusion requirements, potentially confounding the interpretation of perioperative blood loss. While we attempted to standardize our analysis by measuring the change from the immediate preoperative hemoglobin level, the lack of data on these time intervals is a limitation that should be considered when interpreting the results related to hemoglobin drop and transfusion rates. Nevertheless, this study holds academic significance as one of the few studies to directly compare FNS and DHS in a real-world clinical setting for elderly patients with osteoporotic, stable femoral neck fractures.

Conclusions

In conclusion, for the treatment of stable femoral neck fractures in the elderly, internal fixation with FNS provides comparable rates of union, functional recovery, and complications when compared to the traditional DHS, while offering the distinct advantage of a significantly shorter operation time. Therefore, FNS appears to be a promising clinical alternative that is both effective and safe, capable of achieving stable fixation while reducing the surgical burden on the patient. However, given the study's limitations, particularly the sample size, these findings should be considered preliminary. Future large-scale, prospective, randomized controlled trials are warranted to corroborate these findings and provide more definitive conclusions.

Article Information

Author contribution

Conceptualization: BWM, KJL. Data curation: BCC, BWM, KJL. Formal analysis: BCC, BWM. Software: BCC, BWM. Investigation: KJL. Methodology: KJL. Supervision: KJL. Validation: BCC, BWM, JSH. Visualization, JSH. Writing-original draft: KJL, JSH. Writing-review & editing: BCC, BWM, KJL. All authors read and approved the final manuscript.

Conflict of interests

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

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Data availability

Contact the corresponding author for data availability.

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Supplementary materials

None.

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Relationship of lateral malleolar fracture patterns to posterior malleolar fracture morphology in supination-external rotation ankle fractures in Korea: a retrospective cohort study

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Background: Posterior malleolar fractures frequently accompany rotational ankle fractures. However, the morphological relationship between lateral and posterior malleolar fractures in supination-external rotation (SER) ankle fractures remains unclear. This study aimed to classify lateral malleolar fracture patterns in SER type 3 and 4 ankle fractures and investigated their associations with posterior malleolar fracture morphology.

Methods: We retrospectively reviewed 132 patients with SER type 3 or 4 ankle fractures and concurrent posterior malleolar fractures between January 2016 and December 2021. Lateral malleolar fractures were categorized as fibular fractures extending <4.5 cm proximal to the ankle joint (102 ankles) or fibular fractures extending ≥4.5 cm proximal to the ankle joint (30 ankles) based on posterior cortex height measured using three-dimensional computed tomography (3D-CT). Posterior malleolar fracture morphology was assessed using the Haraguchi and Bartonicek classifications. Quantitative parameters—including fracture height, angle, and articular involvement—were analyzed using 3D-CT imaging.

Results: Fibular fractures extending ≥4.5 cm proximal to the ankle joint were associated with a significantly higher frequency of Haraguchi type II and Bartonicek types 3 and 4 posterior malleolar fractures. This group also exhibited greater articular involvement (19.2% vs. 12.0%) and posterior cortical height (55.4 mm vs. 24.8 mm) compared to the <4.5 cm group (all P<0.001).

Conclusions: In SER type 3 and 4 ankle fractures, a fibular fracture extending ≥4.5 cm proximal to the ankle joint may be associated with posterior malleolar fractures exhibiting greater articular involvement and medial extension. Preoperative evaluation of the lateral malleolar fracture pattern may provide useful insights into posterior malleolar morphology and assist in surgical planning. However, these findings should be interpreted with caution due to inherent study limitations.

Level of evidence: IV.

Keywords: Ankle fractures; Ankle joint; Retrospective studies; Supination; X-Ray computed tomography

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Introduction

Background

Posterior malleolar fractures account for approximately 40% of all rotational an-

kle fractures [1,2]. The posterior malleolus forms the weight-bearing portion of the tibial plafond, playing a critical role in tibiotalar load transmission and rotational ankle stability [3,4]. Inadequate diagnosis or management of posterior malleolar fractures can lead to persistent instability and subsequent degenerative changes in the ankle joint [5,6].

Accurate preoperative assessment of posterior malleolar fracture size and pattern is essential for optimal evaluation and surgical planning [7]. Historically, fixation was recommended when the fracture fragment involved 25%–30% or more of the articular surface [8-10]. Recent studies, however, emphasize the importance of considering fracture morphology in addition to fragment size when determining surgical indications [11,12]. Factors influencing posterior malleolar fracture morphology include injury mechanism and the anatomical configuration of the fibular incisura [10,13,14]. Despite this, no prior studies have analyzed posterior malleolar fracture morphology in relation to lateral malleolar fracture patterns in supination-external rotation (SER)-type ankle fractures, which are the most frequent cause of such injuries [15].

The Weber classification, based on the location of the anterior cortex of the fibular fracture, designates all SER-type fractures as type B. Previous research has further characterized Weber B-type lateral malleolar fractures. Boden et al. [16] found that fibular fractures extending more than 4.5 cm proximal to the ankle joint are often associated with excessive syndesmotic widening in cadaveric models. Yamaguchi et al. [17] validated this biomechanical threshold in a prospective clinical study. Park et al. [18] also reported that lateral malleolar fractures extending more than 4.5 cm above the joint line have a threefold higher incidence of syndesmotic instability compared to shorter fractures.

Objectives

We hypothesized that fibular fractures extending more than 4.5 cm proximal to the ankle joint would be associated with larger posterior malleolar fragments. This association may provide clinically relevant information for preoperative assessment and surgical planning, particularly in anticipating the need for internal fixation of the posterior malleolus. Therefore, this study classified lateral malleolar fracture patterns in SER type 3 and 4 ankle fractures using three-dimensional computed tomography (3D-CT) and analyzed their association with posterior malleolar fracture morphology.

Methods

Ethics statement

This study was approved by the Institutional Review Board (IRB) of Chonnam National University Hospital (IRB no., CNUH-2025-151).

Study design

This was a retrospective observational study evaluating the relationship between lateral malleolar fracture patterns and posterior malleolar fracture morphology in supination-external rotation (SER) type 3 and 4 ankle fractures. It was described according to the STROBE statement (https://www.strobe-statement.org/).

Setting

We retrospectively analyzed ankle fracture patients treated at our institution between January 2016 and December 2021 at Chonnam National University Hospital, Gwangju, Korea.

All patients underwent preoperative anteroposterior, lateral, and mortise radiographs, as well as 3D-CT scans and at least 1 year of follow-up. CT data were acquired using either a 128-channel (SOMATOM Definition Flash, Siemens) or a 64-channel (Discovery 750 HD, GE Healthcare) CT scanner.

Given the absence of a standard subclassification for lateral malleolar fractures associated with posterior malleolar fractures, we used the 4.5 cm posterior cortex height threshold from previous studies to divide cases into two groups [16-18]. Lateral malleolar fractures were categorized as fibular fracture extending <4.5 cm proximal to the ankle joint (<4.5 cm group) or fibular fracture extending ≥4.5 cm proximal to the ankle joint (≥4.5 cm group) based on posterior cortex height measured using 3D-CT. The injury mechanism was retrospectively classified based on clinical records. Ground-level falls were defined as slips, trips, or missteps on flat surfaces or low steps (e.g., 1–2 stairs), without vertical descent from a significant height. Falls from height were defined as vertical descent injuries from more than 1 m. Motor vehicle collisions and high-impact sports injuries (e.g., soccer, basketball) were also recorded sepa-

rately based on clinical documentation.

All enrolled patients underwent plate fixation for lateral malleolar fracture through a posterolateral approach. Posterior malleolar fixation was performed selectively based on intraoperative assessment. If satisfactory reduction was achieved via ligamentotaxis, screw fixation was performed in an anteroposterior direction. When reduction was insufficient, direct reduction and fixation of the posterior fragment were performed through a posterolateral window using screws or a plate.

Participants

A total of 150 patients (150 ankles) who underwent open reduction and internal fixation for SER type 3 and 4 ankle fractures were initially enrolled. Patients with open fractures, skeletal immaturity, osteoporotic fractures, diabetes-related fractures, polytrauma, or rotational deformities were excluded. Ultimately, 132 patients (132 ankles) met the inclusion criteria and were categorized as <4.5 cm group (102 ankles) or ≥4.5 cm group (30 ankles).

Variables

Primary outcome variable was a Posterior malleolar fracture morphology. Lateral malleolar fracture pattern, defined by posterior cortex height measured on 3D-CT was an exposure variable. Age, sex, body mass index (BMI), and injury mechanism were covariates.

Data sources/measurement

Demographic and clinical data were obtained from electronic medical records. Radiographic data were derived from 3D-CT scans. Radiographic analysis was performed using 3D-CT to assess the characteristics of both lateral and posterior malleolar fractures. Lateral malleolar fracture patterns were determined by measuring the vertical distance between the highest posterior cortex or lowest anterior cortex of the fracture and a line perpendicular to the tibial axis at the distal tibial articular surface. The angle between the posterior cortex of the lateral malleolus and the line connecting the anterior and posterior cortical points was defined as the fracture angle (Fig. 1).

Posterior malleolar fracture morphology was classified according to the Haraguchi and Bartonicek systems (Figs. 2, 3) [19,20]. The peak height of the posterior malleolar fracture was measured as the vertical distance from the highest point of the distal tibial articular surface to the fracture apex in the sagittal plane (Fig. 4A). The articular surface area of the posterior malleolar fragment was calculated using the region of interest tool in a picture archiving and communication system (Maroview 5.4; INFINITT Healthcare) (Fig. 4B). All quantitative radiographic measurements were performed by two orthopedic surgeons; mean values were used. For categorical variables, disagreements were resolved by consensus.

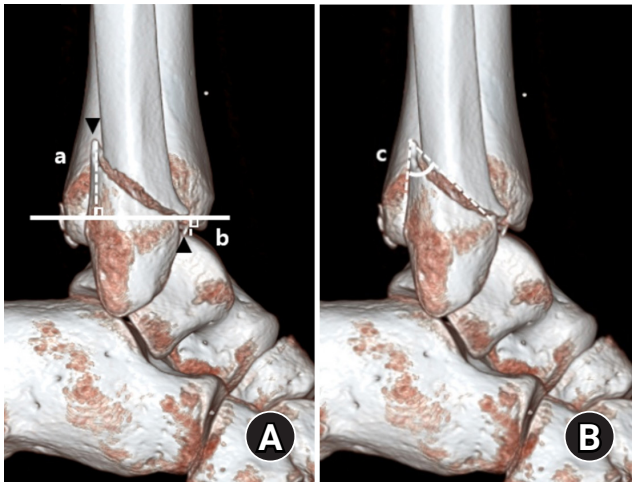

Fig. 1. Radiographic assessment of fracture characteristics. (A) Posterior height (a) and anterior height (b) represent the vertical distances from the highest point of the posterior cortex (▼) and the lowest point of the anterior cortex (▲) of the distal lateral fibula, respectively, to the line perpendicular to the tibial axis that intersects the distal tibial articular plafond. (B) The fracture angle (c) of the lateral malleolar fragment is defined as the angle between the posterior cortex of the lateral malleolus and the line connecting the anterior and posterior cortical points of the fracture.

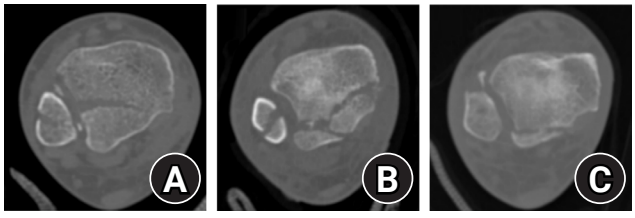

Fig. 2. Haraguchi classification of posterior malleolar fractures. (A) Type I: posterolateral-oblique type. (B) Type II: medial-extension type. (C) Type III: small-shell type.

Bias

To reduce confounding bias, multivariate regression anal-

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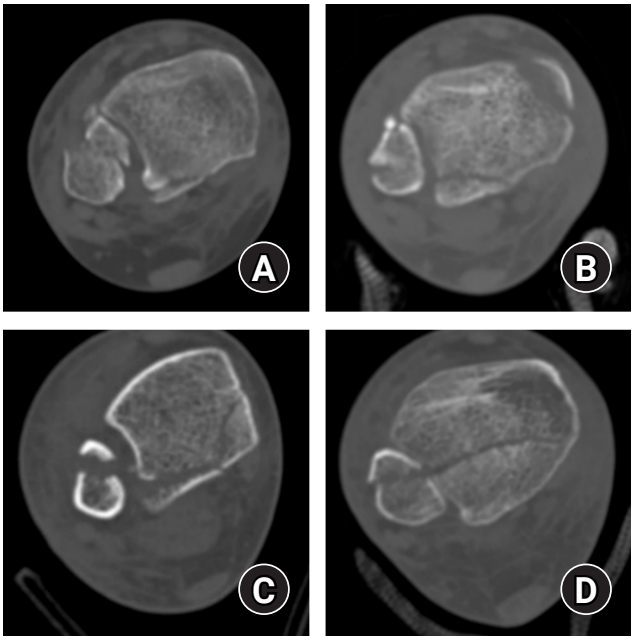

Fig. 3. Bartonicek classification of posterior malleolar fractures. (A) Type 1: extraincisural fragment with an intact fibular notch. (B) Type 2: posterolateral fragment extending into the fibular notch. (C) Type 3: posteromedial two-part fragment involving the medial malleolus. (D) Type 4: large posterolateral triangular fragment.

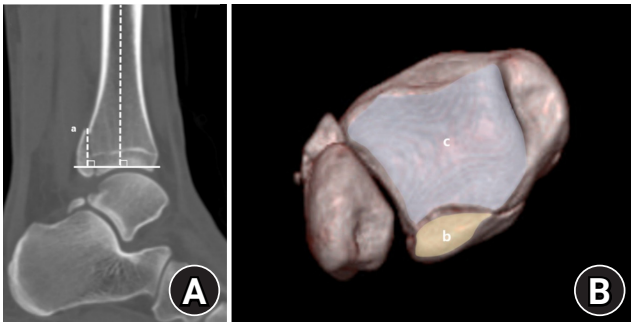

Fig. 4. (A) Peak height (a) of the posterior malleolar fracture is defined as the vertical distance from the highest point of the distal tibial articular plafond to the apex of the posterior malleolar fragment on the sagittal plane. (B) The articular surface area (mm2) of the posterior malleolar fracture fragment (b) was measured using the region of interest tool in a picture archiving and communication system. Articular involvement (%) was calculated as the ratio of the fractured area (b) to the total tibial plafond articular surface area (b+c).

ysis was done by adjusting for age, BMI, and injury mechanism.

Study size

Study size estimation was not done due to the retrospective design. All eligible cases were included in the study period.

Statistical methods

Statistical analysis was conducted using IBM SPSS ver. 29.0 (IBM Corp.). The normality of continuous variables was assessed using the Kolmogorov-Smirnov test, followed by independent t-tests for group comparisons. Categorical variables were analyzed with the chi-square test or Fisher exact test. For radiographic outcomes, multivariable regression analysis was performed to adjust for baseline characteristics, including age, BMI, and injury mechanism, as potential confounders. Interrater reliability was assessed for continuous radiographic parameters using the intraclass correlation coefficient (ICC) with a 95% confidence interval, based on a 2-way random effects model with absolute agreement. ICC values were interpreted as follows: poor (<0.20), fair (0.21–0.40), moderate (0.41–0.60), good (0.61–0.80), and excellent (0.81–1.00).

We performed a receiver operating characteristic (ROC) curve analysis to validate the 4.5 cm threshold for posterior cortex height used to classify lateral malleolar fracture patterns. A posterior malleolar articular surface involvement of ≥25%, which is commonly accepted as a surgical indication, was used as the reference standard [21]. The optimal cut-off value for posterior cortex height was determined using Youden's index. All analyses were reviewed by a statistician. Statistical significance was set at P<0.05.

Results

Participants

Classification by lateral malleolar fracture pattern identified 102 cases (77.3%) of fibular fracture extending <4.5 cm proximal to the ankle joint and 30 cases (22.7%) of fibular fracture extending ≥4.5 cm proximal to the ankle joint (Table 1). The mean age was 54.2 years in the <4.5 cm group and 43.2 years in the ≥4.5 cm group, representing a statistically significant difference (P=0.004). Regarding the injury mechanism, ground-level falls accounted for 85.3% of cases in the <4.5 cm group and 66.7% in the ≥4.5 cm group.

Table 1. Patient demographics and posterior malleolar fracture classification

Variable	<4.5 cm group (n=102)	≥4.5 cm group (n=30)	P-value[a]
Age (yr)	54.2±17.7 (18.0–86.0)	43.2±19.5 (18.0–79.6)	0.004
Sex			0.058
Male	37 (36.3)	17 (56.7)	
Female	65 (63.7)	13 (43.3)	
Laterality, right:left	53 (52.0):49 (48.0)	14 (46.7):16 (53.3)	0.680
BMI (kg/m^2)	24.7±3.1 (18.8–32.1)	25.8±6.0 (21.6–34.1)	0.083
Injury mechanism			0.040
Ground level fall	87 (85.3)	20 (66.7)	
High-impact sports injury	6 (5.9)	6 (20.0)	
Fall from height (>1 m)	3 (2.9)	-	
Motor vehicle collision	6 (5.9)	4 (13.3)	
Follow-up duration (mo)	19.5±12.0 (12.0–78.2)	22.9±16.1 (12.0–72.0)	0.293

Values are presented as mean±standard deviation (range) or number of ankles (%).
BMI, body mass index.
[a]The independent t-test was used for age, BMI, and follow-up duration; the chi-square or Fisher exact test was used for sex and laterality. P<0.05 was considered statistically significant.

In contrast, the ≥4.5 cm group showed higher proportions of high-impact sports injuries (20.0% vs. 5.9%) and motor vehicle collisions (13.3% vs. 5.9%) compared to the <4.5 cm group.

Radiographic outcomes

The <4.5 cm group had a mean anterior cortical height of −1.1 mm, while the ≥4.5 cm group averaged 3.7 mm (Table 2). These data indicate that fibular fracture extending <4.5 cm proximal to the ankle joint typically originated below the distal tibial articular plafond, whereas fibular fracture extending ≥4.5 cm proximal to the ankle joint generally began above it. The ≥4.5 cm group demonstrated greater posterior cortical height (55.4 mm vs. 24.8 mm) and a smaller fracture angle (20.5° vs. 38.1°). Differences in anterior and posterior cortical heights and fracture angle were statistically significant (all P<0.001).

Regarding posterior malleolar fracture morphology, Haraguchi type III (small shell fragment) was more common in the <4.5 cm group, while type II (medial extension) predominated in the ≥4.5 cm group (P<0.001) (Table 2, Fig. 5). Similarly, the Bartonicek classification showed that type 1 (extra-incisural fragment with intact fibular notch) and type 2 (small posterolateral fragment extending into the fibular notch) were more frequent in the <4.5 cm group, whereas type 3 (posteromedial two-part fragment involving the medial malleolus) and type 4 (large posterolateral triangular fragment involving more than one-third of the notch) were predominant in the ≥4.5 cm group (P<0.001).

The mean vertical peak height of the posterior malleolar fracture was greater in the ≥4.5 cm group (21.0 mm) than in the <4.5 cm group (15.2 mm; P=0.002). The articular surface area of the posterior malleolar fragment at the distal tibial articular surface was also significantly larger in the ≥4.5 cm group (242.2 mm^2 vs. 140.7 mm^2; P<0.001). The fragment involved 19.2% of the tibial plafond in the ≥4.5 cm group compared to 12.0% in the <4.5 cm group, indicating significantly greater absolute size and articular involvement in fibular fracture extending ≥4.5 cm proximal to the ankle joint (P<0.001). These results suggest that posterior malleolar fragments are larger in the ≥4.5 cm group.

Interrater reliability

All radiographic parameters in both groups, measured independently by two orthopedic surgeons, demonstrated excellent interrater reliability (Table 3). The highest ICC was observed for the anterior height of the lateral malleolar fracture (0.984, P<0.001), while the lowest was for the articular involvement of the posterior malleolar fracture (0.846, P<0.001).

ROC curve

ROC curve analysis demonstrated an area under the curve of 0.72, indicating acceptable discrimination. The opti-

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Table 2. Comparison of radiographic outcomes between the <4.5 cm and ≥4.5 cm groups

Variable	<4.5 cm group (n=102)		≥4.5 cm group (n=30)		P-value[a]	
	Crude	Adjusted	Crude	Adjusted	Independent t-test	Multivariable analysis
Lateral malleolar fracture						
Anterior height (mm)	−1.1±4.7	−1.1±0.6	3.7±7.2	3.8±1.0	0.002	<0.001
Posterior height (mm)	24.8±7.8	25.1±0.8	55.4±10.4	56.1±1.5	<0.001	<0.001
Fracture angle (°)	38.1±9.1	37.8±0.8	20.5±3.8	21.4±1.5	<0.001	<0.001
Haraguchi classification					<0.001	
I	55 (53.9)		14 (46.7)			
II	9 (8.8)		11 (36.7)			
III	38 (37.3)		5 (16.7)			
Bartonicek classification					<0.001	
1	22 (21.6)		4 (13.3)			
2	48 (47.1)		6 (20.0)			
3	9 (8.8)		11 (36.7)			
4	23 (22.5)		9 (30.0)			
Posterior malleolar fracture						
Peak height (mm)	15.2±8.7	15.2±0.9	21.0±9.1	21.0±1.6	0.002	0.003
Fragment area (mm^2)	140.7±99.5	140.0±10.2	242.2±122.2	244.6±19.5	<0.001	<0.001
Articular involvement (%)	12.0±8.2	11.9±0.8	19.2±9.0	19.5±1.5	<0.001	<0.001

Values are presented as number of ankle (%), mean±standard deviation (crude value), or mean±standard error (adjusted value).
[a]The independent t-test was used to compare continuous variables for lateral and posterior malleolar fractures. Multivariable regression was used to adjust for baseline characteristics, including age, body mass index, and injury mechanism, as potential confounders. The chi-square or Fisher exact test was applied for categorical variables (Haraguchi and Bartonicek classifications). P<0.05 was considered statistically significant.

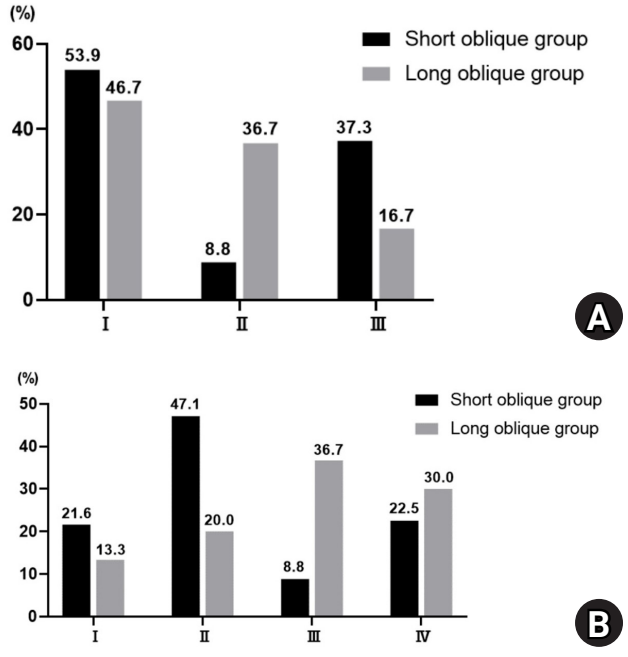

Fig. 5. (A) Distribution of Haraguchi classification types in the <4.5 cm and ≥4.5 cm groups. (B) Distribution of Bartonicek classification types in the <4.5 cm and ≥4.5 cm groups.

mal cut-off value for posterior cortex height was 39.3 mm, yielding a sensitivity of 0.65, specificity of 0.80, and a Youden's index of 0.45 (Fig. 6).

Discussion

Key results

This study is the first to assess the association between lateral malleolar fracture patterns and posterior malleolar fracture morphology in SER type 3 and 4 ankle fractures. The principal finding is that fibular fracture extending ≥4.5 cm proximal to the ankle joint are linked to larger posterior malleolar fragments, greater articular involvement, more frequent medial extension, and higher peak fracture height. These features are commonly considered when determining the need for posterior malleolar fixation. Therefore, identifying a fibular fracture extending ≥4.5 cm proximal to the ankle joint pattern on initial radiographs may provide useful insight into the underlying posterior malleolar morphology and assist in preoperative planning, even before 3D-CT assessment.

Table 3. ICCs for the interrater reliability of radiographic measurements

Interrater reliability	ICC for agreement (95% CI)	Category	P-value
Lateral malleolar fracture (n=132)			
Anterior height (mm)	0.984 (0.977–0.988)	Excellent	<0.001
Posterior height (mm)	0.954 (0.935–0.967)	Excellent	<0.001
Fracture angle (°)	0.902 (0.864–0.929)	Excellent	<0.001
Posterior malleolar fracture (n=132)			
Peak height (mm)	0.888 (0.845–0.919)	Excellent	<0.001
Fragment area (mm^2)	0.913 (0.879–0.937)	Excellent	<0.001
Articular involvement (%)	0.846 (0.784–0.890)	Excellent	<0.001

ICC, intraclass correlation coefficient; CI, confidence interval.

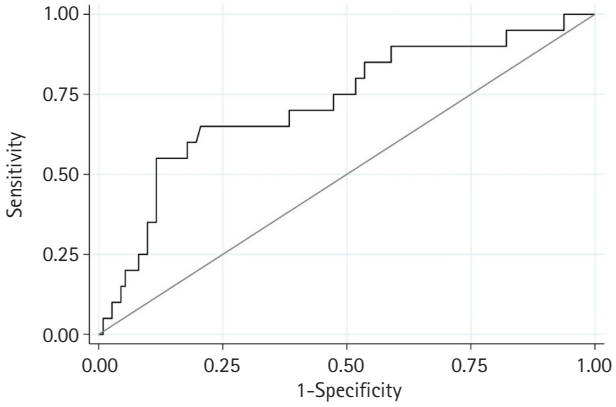

Fig. 6. Receiver operating characteristic curve of posterior cortex height for predicting ≥25% articular involvement of the posterior malleolar fragment. The area under the curve was 0.72, and the optimal cut-off value was 39.3 mm (sensitivity, 0.65; specificity, 0.80; Youden's index, 0.45).

Interpretation/comparison with previous findings

We found that the fibular fracture extending ≥4.5 cm proximal to the ankle joint pattern was more prevalent among younger patients. This may reflect the morphological similarity between fibular fracture extending ≥4.5 cm proximal to the ankle joint—which extend more proximally on the posterior cortex—and Weber C-type fibular fractures, typically observed in pronation-external rotation (PER) ankle injuries. As PER fractures generally result from higher-energy trauma and are more common in young males, it is reasonable to infer that fibular fracture extending ≥4.5 cm proximal to the ankle joint share similar demographic characteristics [22]. This observation is consistent with previous research on posterior malleolar fracture morphology. Yi et al. [13] reported that larger fragments and medial extension types were more frequent in PER than SER injuries. In our study, the ≥4.5 cm group similarly showed more Haraguchi type II and Bartonicek types 3 and 4 fractures, indicating a tendency toward larger, medially extending posterior malleolar fragments. In addition, the proportion of injuries other than ground-level falls was higher in the ≥4.5 cm group (33.3%) than in the <4.5 cm group (14.7%), suggesting that this fracture pattern may be associated with relatively higher-energy trauma.

Posterior malleolar fractures are common, accounting for about 40% of rotational ankle fractures [1,2]. The posterior malleolus forms the weight-bearing portion of the tibial plafond and contributes to the syndesmosis, playing a key role in tibiotalar load transfer and rotational stability [3,4]. Inadequate management can result in complications such as instability and posttraumatic arthritis, leading to poor functional outcomes [23-25]. Solan et al. [26] propose that fixation is often beneficial, as it restores the articular surface and fibular length, enhances syndesmotic stability, and facilitates earlier rehabilitation. Blom et al. [11] further highlighted the importance of fixation, particularly in fractures with medial extension, as these are frequently associated with deep deltoid ligament injuries and a higher risk of persistent instability.

The indications for fixation and optimal surgical approach for posterior malleolar fractures remain debated [19,27]. Traditionally, fixation was advised when more than 25%–30% of the articular surface was involved, based on lateral radiographs [8-10]. However, recent studies have shown that plain radiographs often overestimate fragment size and may be unreliable for assessing articular involvement [28,29]. Lee et al. [7] demonstrated that articular involvement measured on radiographs is frequently overestimated and varies with fracture morphology, under-

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scoring the need for 3D-CT for accurate evaluation. In our study, although the ≥4.5 cm group had significantly greater articular involvement than the <4.5 cm group, mean involvement in both groups was less than 20%. While 3D-CT enables direct measurement of articular involvement, clear surgical guidelines based on fragment size are lacking and require further research.

Limitations

First, its retrospective design and relatively small sample size—particularly the imbalance in group sizes between the two groups—may have limited the strength of the analysis. This imbalance also increases the risk of overinterpretation, especially for findings derived from the smaller group. Second, although two orthopedic surgeons performed the radiographic measurements, only interrater reliability was assessed, and intrarater reliability was not evaluated. Third, although the primary aim of this study was to analyze radiographic morphology rather than clinical results, the absence of clinical outcomes remains a key limitation. This limited the ability to evaluate the association between lateral malleolar fracture pattern and functional outcomes. Fourth, although we used a 4.5 cm posterior cortex height threshold for group classification based on previous literature, our ROC analysis identified an optimal cut-off of 39.3 mm. As this result was derived solely from articular involvement, which is not the only factor guiding fixation decisions for posterior malleolar fractures, and given the limited sample size of our study, further research is warranted to validate and refine these criteria. Finally, although we adjusted for age, BMI, and injury mechanism in the analysis of radiographic outcomes, other unmeasured confounding factors such as bone density may have influenced fracture morphology and were not included in the analysis.

Conclusions

SER type 3 and 4 ankle fractures with a fibular fracture extending ≥4.5 cm proximal to the ankle joint pattern may be associated with posterior malleolar fragments exhibiting greater articular involvement and more frequent medial extension. Thorough preoperative assessment of the lateral malleolar fracture pattern may suggest underlying posterior malleolar morphology and help inform surgical planning. However, given the small sample size and imbalance between groups, the findings should be interpreted with caution.

Article Information

Author contribution

Conceptualization: JEK, CJP, JYL, KBL, GWL. Data curation: JEK, CJP, GWL. Formal analysis: JEK, CJP, KBL, GWL. Methodology: JEK, CJP. Project administration: JYL, KBL, GWL. Investigation: JEK, CJP. Resources: JEK, CJP. Software: GWL. Supervision: KBL, GWL. Writing-original draft: JEK, GWL. Writing-review & editing: JEK, JYL, KBL, GWL. All authors read and approved the final manuscript.

Conflict of interests

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

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None.

Data availability

Contact the corresponding author for data availability.

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Supplementary materials

None.

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Hook plate versus periarticular-type volar locking plate for distal radius fractures involving the volar lunate facet in Korea: a retrospective cohort study

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Background: This study investigated the clinical and radiographic outcomes of hook plate (HP) fixation for volar lunate facet fractures, comparing them with periarticular-type volar locking plates (PVLPs).

Methods: A retrospective review was conducted on 24 patients with distal radius fractures involving volar lunate facet fragments who underwent surgery between January 2016 and April 2021. Patients were divided into two groups: HP (n=12) and PVLP (n=12). Radiographic union, wrist range of motion, Disabilities of the Arm, Shoulder and Hand (DASH) scores, and implant-related complications were compared. Statistical analyses included the Mann-Whitney U test and Fisher exact test.

Results: Radiographic union was achieved in all patients (100%), without secondary displacement or hardware failure. No significant differences were observed between the two groups in wrist flexion (P=0.152), extension (P=0.832), pronation (P=0.792), or supination (P=0.328). The mean DASH scores were 12.8±5.5 in the HP group and 14.6±6.0 in the volar plate group (P=0.449). One patient in the HP group experienced mild flexor tendinopathy that resolved with conservative management. No cases of tendon rupture or early reoperation were reported.

Conclusions: Fixation of volar lunate facet fractures using a HP yielded clinical and radiographic outcomes comparable to those of PVLPs, with a low rate of complications and reliable bony union. Due to its mechanical stability, compatibility with standard surgical approaches, and low risk of flexor tendon irritation, the HP may serve as a valuable alternative for managing volar lunate facet fractures.

Level of evidence: IV.

Keywords: Wrist injuries; Internal fracture fixation; Radius fractures; Bone plates; Lunate bone

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Introduction

Background

Distal radius fractures are one of the most common fractures seen in elderly patients. However they are known to be particularly challenging to treat when accompanied by a volar lunate facet fragment [1]. Anatomically, the short radiolunate ligament and the anterior distal radioulnar ligament originate from the edge of the volar lunate facet, and their deforming forces can cause dislocation of the fracture fragment if fixation is insufficient, resulting in wrist joint instability [2].

The volar lunate facet of the distal radius is a critical structure that contributes to load transmission through both the radiocarpal and distal radioulnar joints and serves as the primary restraint against volar subluxation of the distal articular surface [2-4]. Inadequate reduction and fixation of this fragment may result in complications such as secondary displacement, underscoring the need for thorough preoperative planning and evaluation [1,5,6]. Moreover, the anatomical complexity of the distal radius adds to the technical challenge of achieving stable fixation, particularly for surgeons with limited experience in managing intraarticular fractures [1].

Several prior studies have explored the option of extending or positioning the volar locking plate more proximally to provide enhanced support to the ulnar aspect of the distal radius, particularly the lunate facet [1]. While this modification can reinforce fixation in that region, placing the plate distal to the watershed line to address very distal fractures may lead to complications such as flexor tendon irritation, tendinitis, or even rupture [3]. Furthermore, in cases where the fracture fragment is too small, the standard volar locking plate may fail to offer adequate stability.

Numerous surgical techniques have been explored to achieve stable fixation of volar lunate facet fragments in distal radius fractures, yet their outcomes have been inconsistent and often accompanied by complications such as flexor tendon irritation or rupture [7-10]. A promising alternative involves the use of a hook plate (HP), a hook-shaped metal implant originally developed for distal ulnar fixation. This device has demonstrated favorable outcomes in securing the lunate facet fragment and promoting bone union, while minimizing the risk of complications [9,11]. The HP is well suited in terms of size, contour, and length for supporting the volar ulnar corner of the distal radius. It also offers technical convenience, as it can be implanted through a standard volar approach without the need for additional instruments or dorsal exposure.

Objectives

The purpose of this study was to evaluate the clinical and radiographic outcomes of internal fixation using a HP in distal radius fractures involving the volar lunate facet fragment. To validate its effectiveness, we compared outcomes with those of periarticular-type volar locking plate (PVLP) fixation. We hypothesized that HP fixation would provide stable fragment control, facilitate reliable union, and achieve comparable functional outcomes, while minimizing implant-related complications such as flexor tendon irritation.

Methods

Ethics statement

This study was approved by the Institutional Review Board (IRB) of at Myongji Hospital (IRB No., 2022-11-026). The requirement for informed consent was waived due to the retrospective nature of the study.

Study design

It is a retrospective cohort study based on chart review from the electronic medical records. It was described according to the STROBE statement (https://www.strobe-statement.org/).

Setting

It was conducted at Myongji Hospital Between January 2016 and April 2021. Surgical procedures were performed under general anesthesia with the patient in the supine position and a pneumatic tourniquet applied to the upper limb. A modified Henry approach was used [12]. After incising the sheath of the flexor carpi radialis tendon, the tendon was retracted ulnarly to expose the floor of its compartment. The pronator quadratus was then incised along its ulnar border and elevated subperiosteally to expose the fracture site. Following hematoma evacuation and debridement, reduction was achieved using reduction forceps. In the HP group, the volar lunate facet fragment was reduced using reduction forceps and stabilized with a HP applied to the volar-ulnar corner of the distal radius. Screws were inserted for fixation, and if fragment size permitted, additional screws were used to secure the lunate facet directly (Figs. 1, 2). Additional fixation, such as a LCP-L distal radius plate (Fig. 3A), percutaneous pinning (Fig. 3B), or percutaneous pinning with external fixation (Fig. 3C), was applied as required based on fracture complexity and the presence of radial styloid or articular comminution. In the PVLP group, fracture reduction and fixation were performed using the PVLPs alone, without HP application (Fig. 4). In all cases, intraoperative fluoroscopy was used to confirm reduction and implant positioning, followed by irrigation and layered

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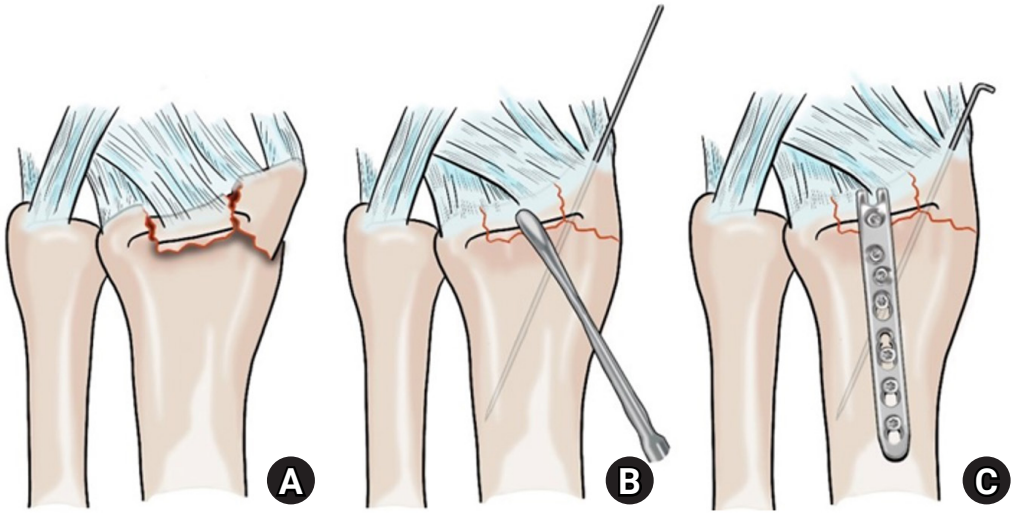

Fig. 1. Surgical procedure. (A) Volar lunate facet fragment after distal radius fracture. (B) Reduction of the fragment and temporary fixation with a Kirschner wire. (C) Application of a hook plate to the volar aspect of the distal radius; additional percutaneous pinning was performed when plate fixation alone was insufficient.

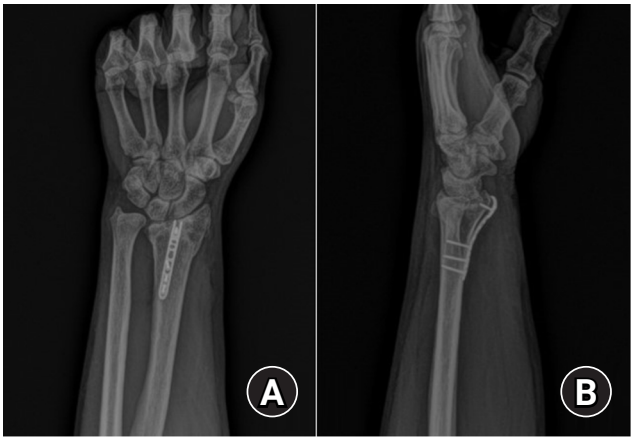

Fig. 2. Postoperative radiographs (A) anteroposterior and (B) lateral: a 2.0 mm locking compression plate distal ulnar hook plate (Synthes) used for fixation in a distal radius fracture with a volar lunate facet fragment.

wound closure.

Participants

Adult patients aged 18 years or older who underwent surgical treatment for distal radius fractures with volar lunate facet fragments were screened for eligibility.

Fractures were classified according to the AO/OTA classification system, and only those classified as type B3, C2, or C3 were included. Patients were excluded if they had open fractures, a history of previous ipsilateral wrist surgery,

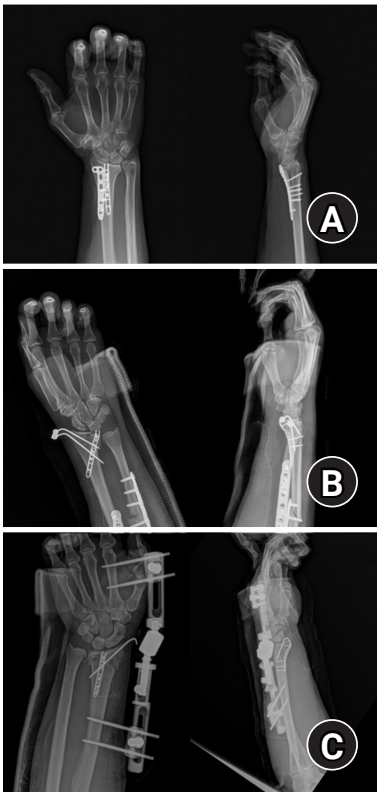

Fig. 3. Postoperative radiographs (anteroposterior and lateral). (A) Volar articular marginal fragment of the distal radius fixed by two plates: a standard 2.4 mm LCP-L distal radius plate (Synthes) and a 2.0 mm locking compression plate distal ulnar hook plate (Synthes). (B) Additional percutaneous pinning after plating. (C) Additional percutaneous pinning and external fixator after plating.

or incomplete radiographic or clinical follow-up. Among them, patients who had a minimum follow-up period of 6 months after surgery were included. A total of 24 patients met the inclusion criteria and were divided into two groups based on the fixation method used. The HP group included 12 patients who underwent fixation with a 2.0 mm locking compression plate (LCP) distal ulnar HP (Synthes), with or without adjunctive fixation. Based on the fracture configuration, additional fixation such as a 2.4 mm LCP-L distal radius plate (Synthes), percutaneous pinning, or percutaneous pinning with external fixation was applied as necessary. The PVLP group consisted of 12 patients treated with PVLP alone. In this group, implants included the 2.4 mm variable angle LCP volar rim distal radius plate (Synthes) and the Acu-Loc volar distal radius plate (Acumed).

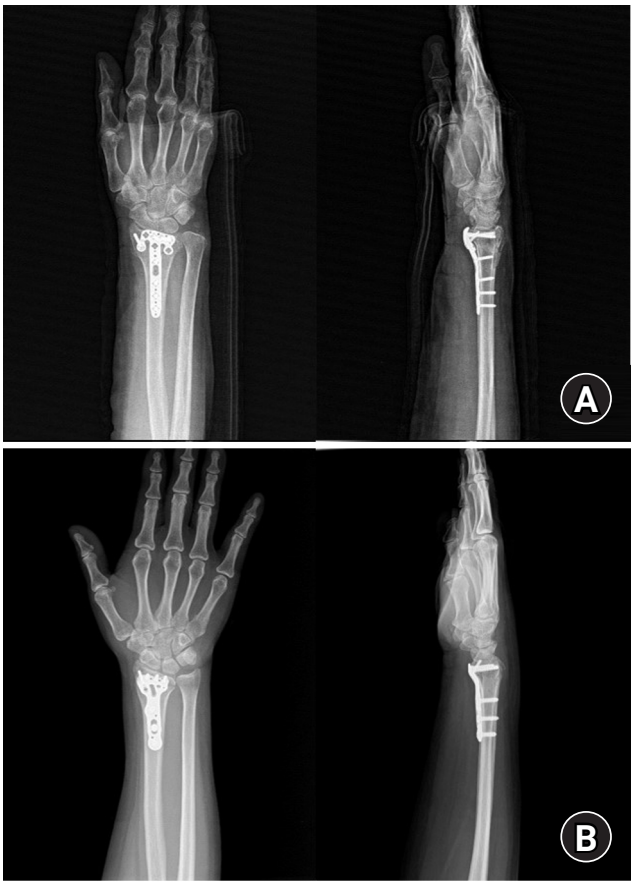

Fig. 4. Postoperative radiographs (anteroposterior and lateral). (A) A 2.4 mm variable angle locking compression plate volar rim distal radius plate (Synthes) used for fixation in a distal radius fracture with a volar lunate facet fragment. (B) Acu-Loc volar distal radius plate (Acumed) used for fixation in a distal radius fracture with a volar lunate facet fragment.

Variables

The primary outcome was radiographic union of the volar lunate facet fragment. Secondary outcomes included active range of motion, Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire, implant-related complications (including implant failure, infection, tendon rupture, flexor tendinopathy), and the need for reoperation.

Data sources/measurement

Standard anteroposterior and lateral radiographs were obtained at 2, 4, 6, and 12 weeks postoperatively to evaluate maintenance of reduction and radiographic union. At the final follow-up visit, wrist range of motion—including flexion, extension, pronation, and supination—was measured using a goniometer by an independent evaluator (Fig. 5).

Bias

To minimize measurement bias, range of motion was assessed by an independent evaluator not involved in the surgery. All radiographs were reviewed by two orthopedic surgeons independently.

Study size

No sample size estimation was performed; all eligible pa-

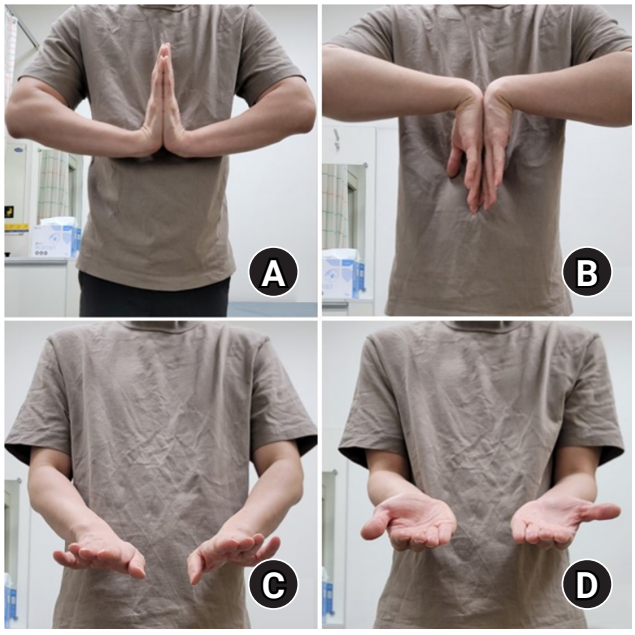

Fig. 5. Wrist range of motion—including (A) flexion, (B) extension, (C) pronation, and (D) supination—was measured at the final follow-up.

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tients during the study period were included.

Statistical methods

Demographic variables, fracture classification, fixation method, and clinical outcomes were compared between the HP and PVLP groups. Continuous variables such as range of motion angles and visual analog scale scores were expressed as mean±standard deviation and analyzed using the Mann-Whitney U test. Categorical variables, including union rate and complication incidence, were analyzed using Fisher exact test. A P-value of less than 0.05 was considered statistically significant. All statistical analyses were performed using the IBM SPSS ver. 25.0 (IBM Corp.). There were no missing outcome data; all patients completed clinical and radiographic follow-up.

Results

Participants

A total of 24 patients with distal radius fractures involving volar lunate facet fragments were included in the study, comprising 12 patients in the HP group and 12 patients in the PVLP group. The mean age was 54.9 years (range, 25–77 years) in the HP group and 60.1 years (range, 28–84 years) in the PVLP group. There were eight males and four females in the HP group, and four males and eight females in the PVLP group. According to the AO/OTA classification, eight patients (67%) in the HP group and 11 patients (92%) in the PVLP group had type B3 fractures, one patient (8%) in the HP group and 0 patient in the PVLP group had type C2, while three patients (25%) in the HP and one patient (8%) in the PVLP group had C3 fractures. The mean body mass index (BMI) was 25.1 kg/m^2 (range, 20.8–30.0) in the HP group and 24.2 kg/m^2 (range, 21.2–29.1) in the PVLP group (Table 1).

Radiographic union

In the HP group, all patients underwent internal fixation of the lunate facet fragment using a 2.0 mm LCP distal ulna HP. Among them, two patients (17%) were treated with the HP alone, six patients (50%) received an additional volar locking plate, three patients (25%) underwent adjunctive percutaneous pinning, and one patient (8%) received both percutaneous pinning and external fixation. The choice of additional fixation was based on the severity of articular comminution and the presence of radial styloid fractures. No statistically significant differences in union rate were found among the different fixation techniques (P=1.000) (Table 2).

In the PVLP group, all patients underwent internal fixation using a PVLP without application of a HP. The implants used included the 2.4 mm variable angle LCP volar rim distal radius plate (Synthes) in seven patients and the Acu-Loc volar distal radius plate (Acumed) in five patients. No statistically significant difference in union rate was found among the different plate types (P=1.000) (Table 3).

Postoperative radiographs obtained at 2, 4, 6, and 12 weeks demonstrated that all patients with available follow-up maintained stable reduction without displacement of the lunate facet fragment. Radiographic union was con-

Table 2. Fixation techniques and radiographic union rate in the hook plate (HP) group

Variable	HP group (n=12)
Hook plate only	2
Hook plate+volar locking plate (LDRS)	6
Hook plate+percutaneous pinning	3
Hook plate+pinning and external fixation	1
Radiographic union rate (%)	100
Union rate comparison among the techniques	P=1.000

LDRS, locking distal radius system.

Table 1. Demographic characteristics

Variable	HP group (n=12)	PVLP group (n=12)	P-value
Age (yr)	54.9±13.8	60.1±15.1	0.392
BMI (kg/m^2)	25.1±3.0	24.2±2.8	0.436
Sex (male:female)	8 (67):4 (33)	4 (33):8 (67)	0.221
Dominant hand (right:left)	7 (58):5 (42)	11 (100):0 (0)	0.056
AO type (B3:C2:C3)	8 (67):1 (8):3 (25)	11 (92):0 (0):1 (8)	0.290

Values are presented as mean±standard deviation or number (%)
HP, hook plate; PVLP, periarticular type volar locking plate; BMI, body mass index.

Table 3. Fixation techniques and radiographic union rate in the PVLP group

Variable	PVLP group (n=12)
Synthes (2.4-mm variable angle LCP volar rim distal radius plate)	7
Acumed (Acu-Loc volar distal radius plate)	5
Radiographic union rate (%)	100
Union rate comparison among the techniques	P=1.000

PVLP, periarticular type volar locking plate; LCP, locking compression plate.

firmed in all patients (100%) in both groups. Computed tomography was not routinely performed before implant removal; instead, articular congruency was assessed using plain radiographs obtained prior to hardware removal, including anteroposterior, both oblique, and lateral views. No malunion was found, and articular congruency was intact in both groups. None of the patients in either group demonstrated secondary displacement or hardware loosening during the follow-up period (Tables 2, 3).

Functional outcomes

Functional outcomes were evaluated at the final follow-up. The average wrist range of motion at final follow-up was as follows: in the HP group, flexion was 80.0°±0.0°, mean extension was 65.0°±10.0°, mean pronation was 86.7°±8.9°, and mean supination was 80.0°±0.0°; in the PVLP group, flexion was 78.3°±3.9°, extension 64.2°±9.0°, pronation 87.5°±6.2°, and supination 79.2°±2.9°. There were no statistically significant differences in range of motion between the two groups (respectively, P=0.152, P=0.832, P=0.792, P=0.328). The mean DASH scores were 12.8±5.5 in the HP group and 14.6±6.0 in the PVLP group. There were no statistically significant differences in the mean DASH scores between the two groups (P=0.449) (Table 4).

Complications

No patient experienced major complications such as implant failure, infection, or tendon rupture. One individual in the HP group, who had both a HP and a volar locking plate, developed mild flexor tendinopathy. The symptoms were managed with conservative measures until the scheduled implant removal. The early reoperation rate was zero in both groups. After solid bone healing was verified, we removed the hardware in every case—on average, 10.8±3.3 months after the index surgery in the HP group and 10.4±3.3 months in the PVLP group (P=0.805) (Table 5).

Table 4. Comparison of wrist range of motion and functional outcomes between HP and PVLP groups

Variable	HP group	PVLP group	P-value
Flexion (°)	80.0±0.0	78.3±3.9	0.152
Extension (°)	65.0±10.0	64.2±9.0	0.832
Pronation (°)	86.7±8.9	87.5±6.2	0.792
Supination (°)	80.0±0.0	79.2±2.9	0.328
DASH	12.8±5.5	14.6±6.0	0.449

Values are presented as mean±standard deviation.
HP, hook plate; PVLP, periarticular type volar locking plate; DASH, Disabilities of the Arm, Shoulder and Hand.

Table 5. Comparison of complications and reoperation outcomes between HP and PVLP groups

Variable	HP group	PVLP group	P-value
Overall	1	0	1.0
Implant failure	0	0	-
Infection	0	0	-
Tendon rupture	0	0	-
Flexor tendinopathy	1	0	1.0
Early reoperation	0	0	-
Hardware removal timing (mo), mean±SD	10.8±3.3	10.4±3.3	0.805

HP, hook plate; PVLP, periarticular type volar locking plate; SD, standard deviation.

Discussion

Key results

To evaluate the clinical and radiographic outcomes of internal fixation, 24 patients were analyzed, evenly divided between the HP and PVLP groups. Radiographic union was achieved in all patients without displacement, malunion, or hardware failure. Wrist range of motion and DASH scores did not differ significantly between the groups. One HP patient developed mild flexor tendinopathy that resolved conservatively. No infections, tendon ruptures, or early reoperations occurred. Hardware removal was performed in all patients after solid healing.

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Interpretation/comparison with previous studies

The volar lunate facet serves as a critical structure for both radiocarpal and distal radioulnar joint stability. Due to the anatomical location and ligamentous attachments, even small displacement can compromise wrist function and lead to treatment failure if not adequately reduced and stabilized [3]. Moreover, the load on the lunate facet increases during functional forearm postures, and inadequate fixation of the volar margin fracture fragment can lead to displacement due to deformational stress [3].

Achieving anatomical reduction and stable fixation of the volar lunate facet fragment is technically demanding, particularly for less experienced surgeons. The widely used modified Henry approach may be limited in providing clear visualization of the volar-ulnar aspect of the distal radius [12]. In particular, excessive retraction of soft tissues to improve access can increase the risk of median nerve injury [12]. To address this issue, Tordjman et al. [13] proposed a palmar-radial approach that utilizes the interval between the flexor tendons and neurovascular structures to improve access to the ulnar side of the distal radius while minimizing retraction-related complications.

Despite advancements in volar locking plate design, most implants are constrained to placement proximal to the watershed line due to their size and shape. When placed more distally to support lunate facet fragments, volar plates may cause flexor tendon irritation, tendinosis, or even rupture [7,8]. Several alternative techniques have been developed to overcome these limitations. For example, O'Shaughnessy et al. [9] designed a volar HP specifically for lunate facet support, though some patients required early plate removal due to tendon irritation. Moore et al. [14] introduced a spring-wire augmentation technique, and Minato et al. [10] proposed loop-wiring fixation for volar rim fragments; however, these approaches often entail technical complexity or increased risk of tendon injury. Similarly, Jeon et al. [5] used tension band wiring through the posterior cortex, but reported cases of extensor tendon irritation. Imatani et al. [11] described the plate buttress and double-tiered subchondral support (PD) technique using an anatomical low-profile volar plate, which showed favorable outcomes but still requires a dedicated implant system.

In contrast, the present study utilized a HP, originally designed for distal ulna. Its hook structure provided direct buttress support to the volar-ulnar corner of the distal radius, especially in cases where the fragment was too small or distal to allow secure fixation with locking screws alone. Importantly, the narrower width and compact shape of the HP make it less likely to impinge on the flexor tendons although it crosses the watershed line; whereas only one patient in our study experienced mild flexor tendinopathy in the HP group, which resolved with conservative treatment and did not necessitate early implant removal. No cases of flexor tendon rupture, hardware failure, or early reoperation were observed.

Furthermore, the HP can be applied using a single volar approach, avoiding the need for dorsal dissection or complex implant setups. Because it is a readily available and commonly stocked implant, it may be a particularly attractive option in cases where specialized fixation systems such as the PD plate is not available. Clinical and radiographic outcomes in the HP group were comparable to those observed in the PVLP group, with similar union rates, range of motion, DASH scores, and complication profiles.

Limitations

First, due to its retrospective design, there is a potential for selection bias. The small number of cases also limits the ability to detect subtle differences in clinical outcomes. Another limitation is that the PVLP group included more complex distal radius fractures, not just isolated volar lunate facet fractures. This mix of cases may have affected the comparison between the two fixation methods. However, such inclusion reflects real clinical practice, where PVLPs are often used for multifragmentary intraarticular fractures involving the lunate facet. Despite these limitations, the findings offer useful insight into the practical strengths and weaknesses of using a HP for volar marginal fragment fixation.

Conclusions

Using a HP to fix distal radius fractures that involve the volar lunate facet showed good clinical and radiographic results, similar to those seen with PVLPs. The HP gave solid buttress support to the lunate facet, led to reliable bone healing, and had few complications. Since this implant is easy to use through a standard volar approach, is commonly available in most operating rooms, and causes little risk of flexor tendon irritation, it can be a useful option—

especially when the fracture fragment is small or located very distally. Larger, prospective studies will be helpful to confirm these findings.

Article Information

Author contribution

Conceptualization: JHK. Data curation: HJP, JHK. Formal analysis: HJP, JHK. Supervision: JHK. Validation: JHK. Writing-original draft: HJP. Writing-review & editing: HJP, JHK. All authors have read and approved the final version of the manuscript.

Conflict of interests

Joo-Hak Kim 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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Supplementary materials

None.

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Instructions for authors

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1. GENERAL INFORMATION

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

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

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

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The journal adheres to the guidelines for research and publication described in the Committee on Publication Ethics (COPE) Guidelines (https://publicationethics.org/resources/guidelines) the ICMJE Recommendations (https://www.icmje.org), and the Good Publication Practice Guideline for Medical Journals (https://www.kamje.or.kr/board/view?b_name=bo_publication&bo_id=13). Furthermore, all processes addressing research and publication misconduct shall follow the flowchart of COPE (https://publicationethics.org/resources/flowcharts). Any attempts to duplicate publications or engage in plagiarism will lead to automatic rejection and may prejudice the acceptance of future submissions.

Statement of Human and Animal Rights

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

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

Protection of Privacy, Confidentiality, and Written Informed Consent

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

Conflict of Interest

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

Originality, Plagiarism, and Duplicate Publication

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

Secondary Publication

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

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

(2) Secondary publication for various other reasons, in the same or another language, especially in other countries, is justifiable and can be beneficial provided that the following conditions are met. The authors

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

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

Authorship

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

- The contributions of all authors must be described. JMT has adopted the CRediT Taxonomy (https://credit.niso.org/) to describe each author's individual contributions to the work. The role of each author should be addressed on the title page.
- Correction of authorship: Requests for corrections in authorship (such as adding or removing authors, or rearranging the order of authors) after the initial manuscript submission and before publication should be explained in writing to the editor, in a letter or email signed by all authors. A completed copyright assignment form must be submitted by every author.
- Role of corresponding author: The corresponding author takes primary responsibility for communication with the journal during the manuscript submission, peer review, and publication process. The corresponding author typically ensures that all of the journal's administrative requirements, such as providing the details of authorship, ethics committee approval, clinical trial registration documentation, and conflict of interest forms and statements, are properly completed, although these duties may be delegated to one or more co-authors. The corresponding author should be available throughout the submission and peer-review process to respond to editorial queries in a timely manner, and after publication, should be available to respond to critiques of the work and cooperate with any requests from the journal for data, additional information, or questions about the article.
- Contributors: Any researcher who does not meet all four ICMJE criteria for authorship discussed above but contributes substantively to the study in terms of idea development, manuscript writing, conducting research, data analysis, and financial support should have their contributions listed in the Acknowledgments section of the article.

Process for Managing Research and Publication Misconduct

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

Editorial Responsibilities

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

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

Artificial Intelligence (AI) Guideline

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

- AI cannot be listed as an author: AI tools cannot be listed or cited as authors due to their inability to take responsibility for errors.
- Reliability and responsibility in AI use: Authors are responsible for ensuring the reliability of their papers when using AI tools and must take full responsibility for any plagiarism or false information generated by AI. Furthermore, AI-generated content cannot be cited as a primary source.
- Disclosure of AI use: Authors must disclose the use of AI tools at the time of manuscript submission. This disclosure should include the specific tools used, their model names, versions, manufacturers, and the role of the AI in the process. This information should be included in the Methods or Acknowledgments section, with detailed prompts included where relevant.
- Prohibition on AI-generated images and videos: AI-generated images or videos, which lack societal consensus on copyright, cannot be included in submitted manuscripts. However, exceptions may be made if AI is essential to the research design or methodology, in which case it must be explained in the Methods section.
- Restrictions for peer reviewers: Peer reviewers are prohibited from uploading manuscripts to external AI tools during the review process. If AI tools are used to support any part of the review, reviewers must transparently disclose this in their peer review reports.
- Editor's authority: the editor may refuse to proceed with the review of a paper if inappropriate use of AI is detected. Additionally, this policy may evolve in response to advancements in technology and societal agreements.

4. EDITORIAL POLICY

Copyright

Open-Access License

Article Sharing (Author Self-Archiving) Policy

JMT is an open-access journal, and authors who submit manuscripts to JMT can share their research in several ways, including on preprint servers, social media platforms, at conferences, and in educational materials, in accordance with our open-access policy. However, it should be noted that submitting the same manuscript to multiple journals is strictly prohibited.

Registration of Clinical Trial Research

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

Data Sharing Policy

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

- Clinical Trials: JMT accepts the ICMJE Recommendations for data sharing statement policy. Authors may refer to the editorial, "Data Sharing Statements for Clinical Trials: A Requirement of the International Committee of Medical Journal Editors," in the Journal of Korean Medical Science (https://dx.doi.org/10.3346/jkms.2017.32.7.1051). Archiving Policy In accordance with the Korean Library Act, the full text of the JMT can be archived in the National Library of Korea (https://seoji.nl.go.kr/archive). JMT provides electronic archiving and preservation of access to the journal content in the event the journal is no longer published, by archiving in the National Library of Korea (https://www.nl.go.kr/archive/search.do) and the National Library of Korea can permanently preserve submitted JMT papers.

Preprint Policy

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

5. MANUSCRIPT SUBMISSION AND PEER-REVIEW PROCESS

Online Submission

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

Screening after Submission

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

Peer-Review Process

All papers, including those invited by the Editor, are subject to peer review. Manuscripts will be peer-reviewed by two accredited experts in the musculoskeletal trauma care with one additional review by prominent member of our Editorial Board. The editor is responsible for the final decision whether the manuscript is accepted or rejected.

- The journal uses a double-blind peer-review process: the reviewers do not know the identity of the authors, and vice versa. During the peer-review process, reviewers may interact directly or exchange information (e.g., via submission systems or email) only with the editor, which is known as "independent review."
- JMT's average turnaround time from submission to decision is 4 weeks.
- Decision letter will be sent to corresponding author

via registered email. Reviewers can request authors to revise the content. The corresponding author must indicate the modifications made in their item-by-item response to the reviewers' comments. Failure to resubmit the revised manuscript within 4 weeks of the editorial decision is regarded as a withdrawal.

- The editorial committee has the right to revise the manuscript without the authors' consent unless the revision substantially affects the original content.
- After review, the Editorial Board determines whether the manuscript will be accepted for publication. Once rejected, the manuscript does not undergo another round of review.
- All articles in JMT include the dates of submission, revision, acceptance, and publication on their article page. No information about the review process or editorial decision process is published on the article page.

Submission by Editors

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

The conflict of interest declaration should be added as follows.

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

Feedback after Publication

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

Appeals of Decisions

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

6. MANUSCRIPT PREPARATION

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

General Requirements

- All manuscripts should be written in English.
- The manuscript must be written using Microsoft Word and saved as ".doc" or ".docx" format. The font size should be 12 points. The body text must be left-aligned, double-spaced, and presented in a single column. The left, right, and bottom margins must be 3 cm, but the top margin must be 3.5 cm.
- The page numbers should be placed in Arabic numerals at the center of the bottom margin, starting from the abstract page.
- Neither the authors' names nor their affiliations should appear on the manuscript pages.
- Only standard abbreviations should be used. Abbreviations should be avoided in the title of the manuscript. Abbreviations should be spelled out when first used in the text and the use of abbreviations should be kept to a minimum.
- The names of manufacturers of equipment and non-generic drugs should be given.
- Authors should express all measurements in conventional units, using International System (SI) units.
- P-value from statistical testing should be expressed as capital P.

Reporting Guidelines for Specific Study Designs

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

Types of Manuscripts

- The manuscript types are divided into original articles, 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.
- Case Reports: Case reports should be a report on a single case or an analysis of a few cases to add to the clinical spectrum. Case reports should be written in the following order: title page, abstract (within 200 words), keywords, main body (introduction, case report, and discussion), acknowledgments (if applicable), references (up to 10), tables, figure legends, and figures.
- Technical Tricks: Technical tricks should be written in the following order: title page, abstract (within 150 words), keywords, main body (introduction, technique, and discussion), acknowledgments (if applicable), references (up to 10), tables (if applicable), figure legends, and figures. The total word count should not exceed 1,500 words. A maximum of 3 figures and 1 table are allowed.
- 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
Case Report	Unstructured, 200	1,500	10	NL
Technical Tricks	Unstructured, 150	1,500	10	1 Table/ 3 Figures
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/).
- Author Contributions: The contributions of all authors must be described using the CRediT (https://credit.niso.org/) taxonomy of author roles.
- Conflict of Interest: If there are any conflicts of interest, authors should disclose them in the manuscript. If there are no conflicts of interest, authors should state "None" in

this section.

- 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 obtained and analyzed and how research bias was adjusted.
- Results: The most important study results and analysis should be presented in a logical manner with specific experimental data.
- Conclusions: The conclusions drawn from the results should be described in one to two sentences and must align with the study objective.
- Level of Evidence: Author should make the final determination of the study design and level of evidence based on the Centre for Evidence Based Medicine guidelines. Authors may refer to the definitions in the Level of Evidence table (https://www.cebm.ox.ac.uk/files/levels-of-evidence/cebm-levels-of-evidence-2-1.pdf).

Main Body

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

sis. 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 indicated 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 and 10 for case reports and technical notes.
- All references must be cited in the text. The number assigned to the reference citation is according to the first appearance in the manuscript. References in tables or figures are also numbered according to the appearance order. Reference numbers in the text, tables, and figures should in a bracket ([ ]).
- List all authors when there are six or fewer. When there are seven or more authors, list only the first three authors followed by "et al."
- Authors should be listed by surname followed by initials.
- The journals should be abbreviated according to the style used in the list of journals indexed in the NLM Journal Catalog (http://www.ncbi.nlm.nih.gov/nlmcatalog/journals).
- Overlapping page numbers (e.g., 2025-6) should omit the repeated numerals (e.g., 2025-6 should be written as 2025-2026).
- References to unpublished material, such as personal communications and unpublished data, should be noted within the text and not cited in the References. Personal communications and unpublished data must include the individual's name, location, and date of communication.
- Examples of references are as follows:

① Journal

1. Song HK, Cho WT, Choi WS, Sakong SY, Im S. Acute compartment syndrome of thigh: ten-year experiences from a level I trauma center. J Musculoskelet Trauma 2024;37:171-4.
2. MacKechnie MC, Shearer DW, Verhofstad MH, et al. Establishing consensus on essential resources for musculoskeletal trauma care worldwide: a modified Delphi study. J Bone Joint Surg Am 2024;106:47-55.
3. Raats JH, Ponds NH, Brameier DT, et al. Agreement between patient- and proxy-reported outcome measures in adult musculoskeletal trauma and injury: a scoping review. Qual Life Res 2024 Aug 23 [Epub]. https://10.1007/s11136-024-03766-1

② Book & Book chapter

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

③ Homepage/Web site

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

④ Preprint

7. Sharma N, Sharma P, Basu S, et al. The seroprevalence and trends of SARS-CoV-2 in Delhi, India: a repeated population-based seroepidemiological study [Preprint]. Posted 2020 Dec 14. medRxiv 2020.12.13.20248123. https://doi.org/10.1101/2020.12.13.20248123

For more on references, refer to the NLM's "Samples of Formatted References for Authors of Journal Articles."

https://www.nlm.nih.gov/bsd/uniform_requirements.html#journals.

Figures and Figure Legends

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

- Staining techniques used should be described. Photomicrographs with no inset scale should have the magnification of the print in the legend.
- Papers containing unclear photographic prints may be rejected.
- Remove any writing that could identify a patient.
- If any tables or figures are taken or modified from other papers, authors should obtain permission through the Copyright Clearance Center (https://www.copyright.com/) or from the individual publisher, unless they are from open access journals under the Creative Commons License. For tables or figures from an open access journal, simply verify the source of the journal precisely in the accompanying footnote. Please note the distinction between a free access journal and an open access journal: it is necessary to obtain permission from the publisher of a free access journal for using tables or figures published therein. Examples are shown below:
  Reprinted (Modified) from Tanaka et al. [48], with permission of Elsevier.
  Reprinted (Modified) from Weiss et al. [2], according to the Creative Commons License.

Tables

- Tables should be numbered sequentially with Arabic numerals in the order in which they are mentioned in the text.
- If an abbreviation is used in a table, it should be defined in a footnote below the table.
- Additional information for any clarification should be designated for citation using alphabetical superscripts [a], [b], [c] or asterisks (*) for statistical significance. The explanation for superscript citation should follow these examples: [a]Not tested.
  *P< 0.05, **P< 0.01, ***P< 0.001.
- Tables should be understandable and self-explanatory, without references to the text.
- If a table has been previously published, it should be accompanied by the written consent of the copyright holder, and the footnote must acknowledge the original source.

7. MANUSCRIPT PROCESSING AFTER ACCEPTANCE

Final Version

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