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Original Article

Assessment of Internal Fixation Implants for Treating Vertical Femoral Neck Fractures through Finite Element Analysis

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ABSTRACT

Objective: This research primarily focuses on understanding the application of internal fixation implants in the treatment of Pauwels Type-3 vertical Femoral Neck Fractures (FNF). The main objectives encompass understanding the application of four distinct types of implants, assessing the impact of these fixation techniques on the femur bone, and comparing the efficacy of the implants using finite element analyses (FEA).

Methods: Four types of internal fixation implants were examined: Cannulated screws in the inverted triangle (CSIT). Fixation by four screws. Dynamic hip screw with derotational screw system (DHS+DS). Proximal femoral locking plate system. The comparative effectiveness of these implants was determined using finite element analyses (FEA).

Results: The research revealed that the DHS+DS implant exhibited superior performance when compared to other internal fixation implants.

Conclusion: For the treatment of Pauwels Type-3 vertical FNFs, the DHS+DS implant demonstrates enhanced efficacy, potentially making it the most appropriate technique for such fractures.

INTRODUCTION

Femoral neck fractures (FNFs) are significant health problems and serious injuries worldwide. FNFs may often occur during daily activities and professional life, while fall-induced fractures have the highest incidence rate. Although FNFs may be encountered in young patients after major (high-energy) trauma, they may also be encountered in older patients after minor (low-energy) trauma due to the low physical capacities, sensory attenuation, osteoporosis, and degenerated neuromuscular functionality. According to the World Health Organization, there were almost 2 million FNFs in the 1990s, which will most likely increase about 3 times in the 2050s.[1] Although many patients suffer from FNFs, some problems still need to be confronted regarding the treatment process, and a consensus could not be built on the treatment method of FNFs.

While arthroplasty is preferred for older patients, internal fixation is aimed at young patients.[2,3] However, treating FNFs is mostly challenging for orthopedic surgeons since imperfect treatment approaches would cause complications such as non-union and avascular necrosis.[4,5] Selection of the treatment method mainly depends on the fracture type, specific medical needs of the patient, and risk factors (e.g., lifestyle, nutrition, age, and sex). FNFs are mostly treated with pins, screws, plate and screws, rod and screws, or the arthroplasty operation.[6] The previous studies on FNFs and their treatment have shown that the appropriateness of the treatment method is a significant factor in the healing process of FNFs.

Many studies have focused on FNFs and their treatment. Bonnaire and Weber[7] investigated the 1300 angle plate + cranial screw (1300 ap+s), three cancellous bone screws (3 cbs), dynamic hip screw (DHS), and DHS with an additional lag screw (DHS+ls). Aminian et al.[8] conducted another biomechanical study on vertically oriented FNFs. The study assessed four different fixation techniques; 7.3 mm cannulated screws placed in a triangular configuration (group 1), a 1350 DHS (group 2), a 950 dynamic condylar screw (group 3), and a locking proximal femoral plate (group 4) on 32 cadaveric femurs. Berkes et al.[9] studied catastrophic failure after open reduction internal fixation of FNFs with a novel locking plate implant. Similarly, Enocson and Lapidus[10] focused on FNFs with a vertical orientation, and 136 patients who were operated on using the combination of a sliding hip screw and a superior parallel anti-rotation screw were observed for 4.8 years. Hawks et al.[11] investigated an inverted triangle construct, and a trochanteric lag screw construct was mechanically tested. Araujo et al.[12] evaluated 31 patients were divided into two main groups; the first group consisted of the patients who underwent surgical operation between 3 and 7 days after the fracture, and the second group included the patients who underwent surgical operation between 8 and 18 days after the fracture. These groups were followed-up for 24–50 months. Kuan et al.[13] performed and evaluated the biomechanical stability of FNFs treated by different fixation techniques. In the mechanical tests, fourth-generation synthetic composite femur specimens were vertically loaded with a 6 cm diameter flat stainless steel plate centered over the femoral head. Luo et al.[14] worked on Pauwels Type-3 vertical FNFs, which were treated by modified DHSs. In the study, 17 consecutive patients with Pauwels Type-3 vertical FNFs were treated with the modified DHS and followed up for at least 24 months.

Numerous studies have been conducted on FNFs and their treatment methods. However, limited studies have been performed on the same issue through finite element analyses.[15-19] Considering this necessity, this study mainly focuses on four internal fixation methods for treating Pauwels Type-3 FNFs. Furthermore, it compares these approaches using three-dimensional finite element modeling and analysis.

MATERIALS AND METHODS

Internal Fixation Implants

Many different types of internal fixation implants have been developed for FNFs. However, internal fixation implants can be divided into three major types: Multiple cancellous screws, fixed angle devices that allow sliding/compression, and fixed angle devices that do not allow sliding/compression.[20-22]

In this study, fixation methods are classified into four main groups: (1) Cannulated screws in an inverted triangle (CSIT), (2) fixation by four screws (FFC), (3) DHS with derotational screw system (DHS+DS), and (4) proximal femoral locking plate system (PFLP).

CSIT

CSIT implants are one of the most commonly used methods for treating FNFs. The method is minimally invasive with percutaneous application after closed reduction, which shortens the duration of surgery and does not lead to bleeding. In this study, the positions of three parallel screws form an inverted triangle, and these screws have 7 mm of diameter, 90 mm of length, and 20 mm of terminal thread (Figure 1).

FFC

FFC implants are a less used method than other internal fixation implants. Three of the screws, which are placed in an inverted triangular shape in parallel with the neck, have 7 mm of diameter, 90 mm of length, and 20 mm of terminal thread. The fourth screw, which is placed transversely into the calcar, has 7 mm of diameter, 82 mm of length, and 20 mm of terminal thread (Figure 2).[20]

DHS with derotational screw (DHS+DS)

DHS+DS implants are frequently used in the treatment of Pauwels Type-3 FNFs. In the DHS+DS implant, the derotational screw with 7 mm of diameter, 90 mm of length, and 32 mm of terminal thread was seated parallel to the central screw with 10 mm of diameter, 87 mm of length, and 20 mm of terminal thread. Two cortical screws with 6 mm of diameter, 36 mm of length, and 16.5 mm of terminal thread were preferred to fix the lower side of the plate to the femoral shaft (Figure 3).

PFLP

PFLP implant is another commonly used method for the treatment of intertrochanteric FNFs. In the PFLP implants, two screws with 7 mm of diameter, 90 mm of length, and

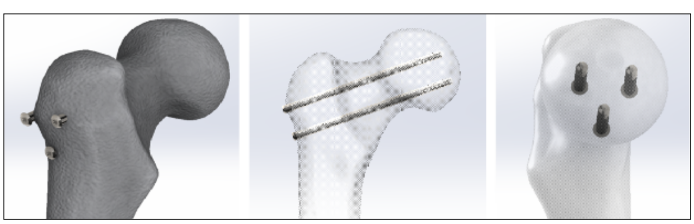

Figure 1. Cannulated screws in an inverted triangle.

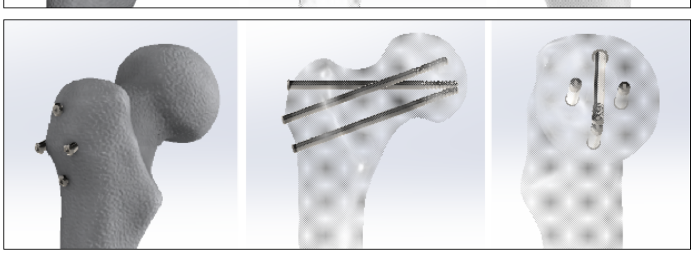

Figure 2. Fixation by four screws.

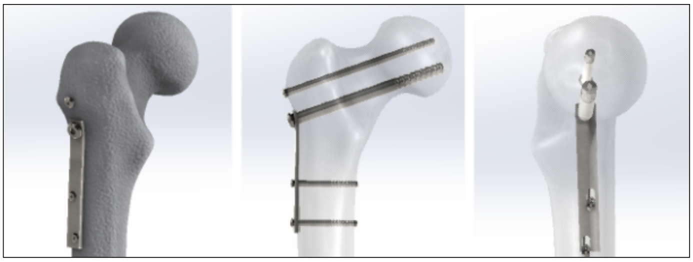

Figure 3. Dynamic hip screw with derotational screw.

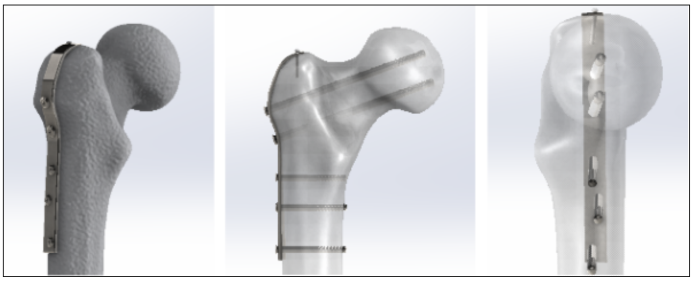

Figure 4. Proximal femoral locking plate.

32 mm of terminal thread were seated parallel to the central screw. Three cortical screws with 6 mm of diameter, 36 mm of length, and 16.5 mm of terminal thread were preferred to secure the lower side of the plate to the femoral shaft (Figure 4). Moreover, a fully threaded screw, which has a 12 mm length and 3 mm diameter, was located in the upper section of the femur.

MODELING

Finite Element Modeling Details

To evaluate the performances of the implant methods, general-purpose finite element software ANSYS Workbench[23] was used to model and analyze the fixation implants. Geometrical properties of the femur bone and internal fixation implants were implemented using the clinical and biomechanical data literature. Mechanical properties were determined, considering previous studies and general assumptions were made due to the complexity involved in the osseous structure.[24-30] Considering suggestions of the previous studies, Young's modulus, Poisson's ratio, and density of the femur bone were modeled as 15 GPa, 0.3, and 0.55 g/cm3, respectively. In comparison, these characteristics of the implants were modeled as 193 GPa, 0.31, and 7.75 g/cm3, respectively. In the finite element model, femur bone and internal fixation implants were numerically modeled using Solid186 elements, which have 20 nodes

Table 1. Critical stresses calculated on the femur

Loading configurations	Internal fixation implants	Maximum shear strength (MPa)
Loading-1	CSIT	4.02
	FFC	4.19
	DHS+DS	5.96
	PFLP	5.86
Loading-2	CSIT	1.61
	FFC	1.80
	DHS+DS	2.96
	PFLP	2.81
Loading-3	CSIT	1.60
	FFC	1.81
	DHS+DS	2.97
	PFLP	2.81
Loading-4	CSIT	3.54
	FFC	4.31
	DHS+DS	5.84
	PFLP	5.52
Loading-5	CSIT	3.65
	FFC	4.25
	DHS+DS	5.49
	PFLP	5.26

and three degrees of freedom per node.

Moreover, tetrahedral elements were used in this study due to the geometrical complexity of the femur bone. In the numerical models, femur bone and implants were discretized with 409289, 426674, 463008, and 472509 solid elements with corresponding 612308, 639602, 692265, and 706716 nodes for the CSIT, FFC, DHS+DS, and PFLP, respectively. Interfaces between the screws and the femur were defined as bonded connections, while the fracture surface on the femur was defined as a frictional surface with a friction coefficient of 0.3.

RESULTS

All models were subjected to five different loading configurations: Vertical displacement load, external rotational loads, internal rotational loads, and their combinations. For the application of boundary conditions of the femur, all nodes at the distal end of the femur were fully fixed in all directions considering the general approach of the previous studies.

Contoured pictures and summarized tables presented finite element analysis (FEA) results since the obtained results were much more complicated to demonstrate each node or element. The study focuses on the stress-based fracture criterion, and only the critical stresses were investigated on the implants (Table 1). Because Pauwels Type-3 fractures[21] were subjected to vertical solid shear force[1] through the analysis, maximum shear stress levels of the femur were evaluated for the femoral behavior. Within the evaluation of the behavior of internal fixation implants, von Mises stress levels were compared in this study. The obtained von Mises stress distributions are provided in Figures 5 and 6.

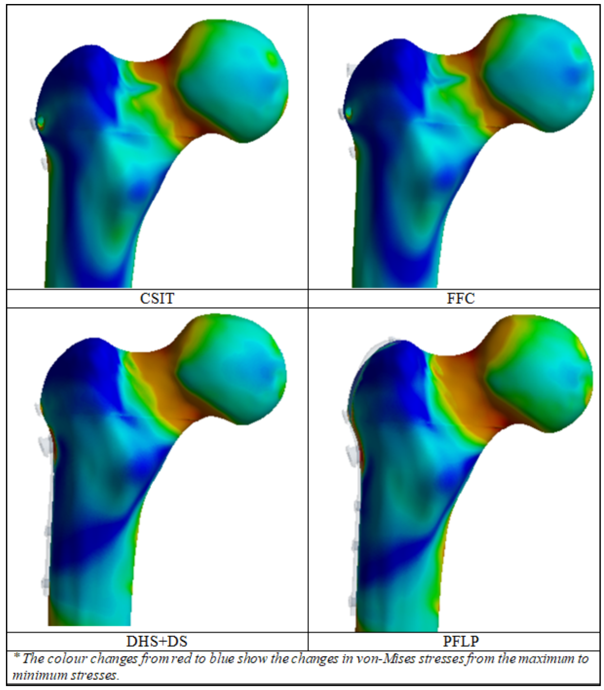

Figure 5. Von-Mises stress distribution obtained from Loading-5.

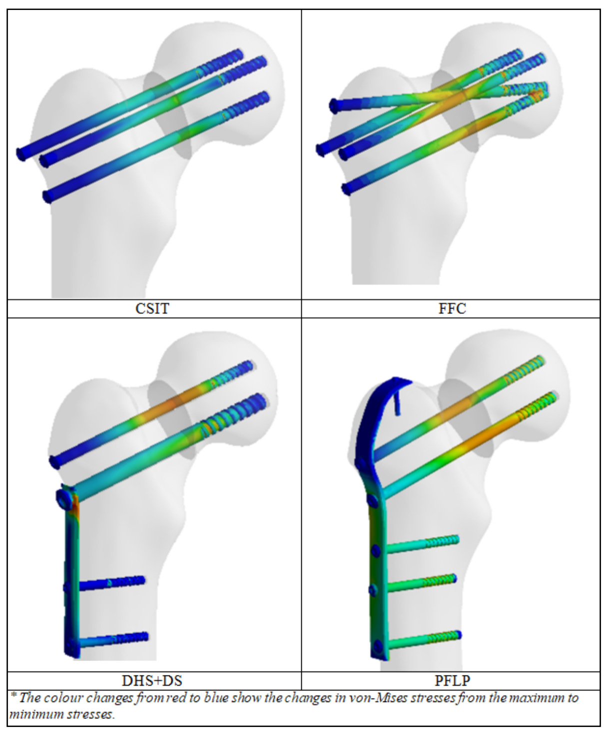

Figure 6. Von-Mises stress distribution from Loading-3.

DISCUSSION

FNFs are among the severe fractures that are difficult to treat in young patients. It is essential that this kind of fracture be treated by the most appropriate method as much as possible. This study focuses on the application of four different internal fixation implants for FNFs using FEA. The FEA results were discussed and compared with each other and also with the outcomes of the previous research in the literature. DHS+DS method provides a stable fixation compared to many methods in vertical FNFs.

Results of the numerical analyses reveal that all of the implant methods improve the healing potential of the femur in terms of the shear stress levels. Regarding the comparison of implant performance of all of the application methods, maximum improvement is acquired for DHS+DS and PFLP implants, while minimum improvement is in CSIT implants. Referencing the shear stress level of CSIT implant, stress values increase in FFC, DHD+DS, and PFLP implants around 4%, 48%, and 45% for Loading-1, 11%, 83%, and 75% for Loading-2, 13%, 84%, and 75% for Loading-3, 21%, 64%, and 55% for Loading-4 and 16%, 50%, and 44% for Loading-5, respectively. Analysis results show that the transverse screw in the FFC increases the maximum shear stress value of the femur compared with CSIT. The results indicate that the transverse screw enhances the shear stress value of the femur by 12% by averaging all of the loading configurations. Considering previous research, similar results were obtained by Gumustas et al.[20] It could also be stated that derotational screw installation improves the shear stress distribution of the implants. Similarly, Bonnaire and Weber[7] observed the structural effect of the derotational screw on the implant systems and determined that the derotational screws improve the structural behavior of the implants.

The highest shear stress levels of the femur are encountered in DHS+DS and PFLP implants. When the results of these implant methods are examined in detail, the plate in the DHS+DS and PFLP implants provides better performance than other implants, CSIT and FFC. Kuan et al.[13] emphasized that the external connection of the screws used in the implant increases the stability of the screws. Concerning the von Mises stresses on the implants of this study, it is seen that critical stresses are concentrated in the transection zone between the screws and plates in the DHS+DS and PFLP implants since the plate do not allow lateral movement.

Conclusions

Application of the most appropriate implant is of great importance for FNFs. The most preferred method for treating FNFs is the internal fixation implants, but deciding the appropriate implant type is still a research topic. This study investigates different fixation techniques for treating Pauwels Type-3 vertical FNFs. Analysis results show that the implant methods play an essential role in the structural behavior of the femur. In contrast, DHS+DS and PFLP methods could be better options than CSIT and FFC for a vertical FNF fixation. It is also important to note that the results obtained from the analyses reveal that critical stresses are concentrated in the transection zone between the screws and plates in DHS+DS and PFLP implants.

Informed Consent

Retrospective study.

Peer-review

Externally peer-reviewed.

Conflict of Interest

None declared.

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Vertikal Femur Boyun Kırıklarının Tedavisinde Fiksasyon Yöntemlerinin Sonlu Eleman Analizi ile Değerlendirilmesi

Amaç: Bu araştırma, Pauwels Tip-3 dikey Femoral Boyun Kırıkları (FNF) tedavisinde iç tespit implantlarının uygulamasını anlamaya özellikle odaklanmaktadır. Ana hedefler dört farklı implantın uygulamasını anlamak, bu tespit tekniklerinin femur kemiği üzerindeki etkisini değerlendirmek ve implantların etkinliğini sonlu eleman analizleri (FEA) kullanarak karşılaştırmaktır.

Gereç ve Yöntem: Dört tip iç tespit implantı incelendi: Ters üçgende kanüllü vidalar (CSIT). Dört vida ile tespit. Derotasyonel vida sistemi ile dinamik kalça vidası (DHS+DS). Proksimal femoral kilitli plaka sistemi. Bu implantların karşılaştırmalı etkinliği sonlu eleman analizleri (FEA) kullanılarak belirlendi.

Bulgular: Araştırma, DHS+DS implantının diğer iç tespit implantlarına göre daha üstün performans sergilediğini ortaya koymuştur.

Sonuç: Pauwels Tip-3 dikey FNF tedavisinde, DHS+DS implantı artırılmış bir etkinlik göstermekte olup, bu tür kırıklar için potansiyel olarak en uygun teknik olabilir.

Anahtar Sözcükler: Femur boyun kırıkları; Pauwels tip 3 kırıklar; sonlu eleman analizi.