

Research Article

Which implant for Pauwels type 2 femoral neck fractures: a biomechanical study

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ABSTRACT

Objective: Femoral neck fractures (FNF) in young patients are relatively rare but can lead to severe complications if not treated appropriately. Pauwels type 2 fractures, characterized by moderate inclination, require surgical stabilization. However, no consensus exists regarding the optimal implant that provides superior biomechanical stability. This study aims to compare the biomechanical properties of 3 different fixation systems for the surgical treatment of Pauwels type 2 FNF.

Methods: A total of 21 bovine femurs of similar age and size were selected and divided into 3 fixation groups: dynamic hip screw (DHS), cannulated screws (CS), and major plate (MP). Each specimen underwent axial compression testing to assess the maximum load-bearing capacity, shear force resistance, and deformation characteristics of the fixation methods.

Results: The results showed that the CS group exhibited the highest shear stress resistance, followed by the DHS group, while the MP group showed significantly lower mechanical strength and elongation ($P < .05$). Although DHS provided substantial stability, CS demonstrated superior overall mechanical performance. In contrast, the MP system showed significantly lower resistance compared to the other 2 fixation methods.

Conclusion: This biomechanical study highlights the importance of implant selection in the management of Pauwels type 2 FNF. Although previous investigations have questioned the adequacy of CS fixation in highly unstable Pauwels type 3 fractures, the results suggest that CS may be a reliable and effective option for the relatively more stable Pauwels type 2 pattern. Because the tests were performed on bovine femur models, which do not fully reflect the structural characteristics of human bone, these findings should be interpreted with caution. Further biomechanical studies using human cadaveric specimens are required to confirm the applicability of these results to clinical practice.

Level of Evidence: N/A.

Introduction

Femoral neck fractures (FNF) are commonly seen in elderly patients; however, FNFs in young adults account for less than 5% of all hip fractures.¹ In elderly patients, FNFs usually result from falls and osteoporosis, whereas in young patients, these fractures are mostly the result of high-energy trauma.¹

In elderly patients, FNFs are usually treated surgically, with arthroplasty being the most common choice, while in younger patients, reduction of the fracture and secure internal fixation are recommended.² The quality of fracture reduction is one of the most important steps in treatment.³ Closed reduction and internal fixation are the preferred approach; however, open reduction may be required if anatomic alignment cannot be obtained.⁴

Despite current fixation techniques and technological advances, many complications can arise in the treatment of FNF in young patients. A recent meta-analysis reported that approximately 20% of patients required a second operation for the treatment of juvenile FNF, and that a significant proportion of these revisions were due to fixation failure.⁴

There is no consensus on the most appropriate fixation material for the surgical treatment of FNF in young patients.⁵ Although many fixation materials are used, such as cannulated screws (CS), dynamic hip screws (DHS), and compression locking plates, their superiority over each other has not been clearly demonstrated.⁶ Pauwels classified FNF into 3 types based on the angle formed by the fracture line with the horizontal plane on the anteroposterior radiograph.⁷ Accordingly, fractures with an inclination of 0°-30° are classified as type 1, fractures with an inclination of 30°-50° are classified as type 2, and fractures with an inclination of more than 50° are classified as type 3.⁷ Biomechanical studies have shown that shear forces and varus stress increase in more steeply angled type 2 and type 3 fractures, which in turn increases the risk of reduction loss, implant failure, and nonunion.⁷

Previous biomechanical studies have primarily focused on highly vertical Pauwels type 3 fractures, whereas biomechanical data on Pauwels type 2 fractures remain limited.^{8,9} However, biomechanical data on Pauwels type 2 fractures with moderate vertical characteristics are limited. This situation complicates the determination of optimal fixation methods for this fracture type, which is common in young adults.

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Recent biomechanical studies have highlighted the importance of fixation stability based on changes in fracture angle, emphasizing the need for comparative data for type 2 fractures.^{10,11}

The aim of this study was to compare the biomechanical performance of the major plate (MP), DHS, and CS in the surgical fixation of Pauwels type 2 FNF.

Material and methods

Specimens and testing setup

In this biomechanical study, 7 specimens were planned for each group. This number is consistent with previous experimental models investigating femoral neck fracture fixation.¹² The selected number of specimens allows for a reliable comparison between detection methods within the applicability limits of mechanical testing. Post-hoc power analysis ($\alpha=0.05$) based on maximum load (Fmax) results showed a statistical power of 0.83, confirming that the sample size was sufficient to detect between-group differences.

Fixation groups

Approval for this study was obtained from Firat University Ethics Committee (2021/05-04) on April 8, 2021. For the purpose of the experiment, 21 bovine femurs were obtained from the same herd, of the same age group, with comparable length and weight. In order to compare the mechanical behavior of different fixation systems in FNF, bovine femurs osteotomized at a 50° inclination were fixed using 3 different fixation systems: DHS, CS, and MP. The mechanical strength of the fixation systems was evaluated by applying axial compression tests to the specimen groups. Informed consent was not required as this study was conducted on bovine bone specimens and did not involve human participants.

Fixation devices

Major plate (TST, İstanbul, Türkiye): The plate has a thickness of 6.5 mm and an inverted triangular configuration. The screws inserted through the plate are 6.5 mm in diameter. It was developed for the fixation of FNF (Figure 1a).

Dynamic hip screw (TST, İstanbul, Türkiye): It is a fixation system consisting of an 8.0 mm thick, 19 mm long, 4.5 mm distal cortical screw and a proximal part made of titanium. It has a neck angle of 135°. It provides up to 20 mm compression. The combination of lag screw and DHS plate allows precise and controlled positioning of the implant. Fixation was achieved using proximal 6.5-mm cancellous screws and distal 4.5-mm cortical screws (Figure 1b).

Cannulated screw (TST, İstanbul, Türkiye): It is a 6.5 mm thick system developed for fracture fixation of large and small bones, fusion, and

osteotomy applications. The screws are cancellous threaded. In addition to 32 mm threaded screws, there are also washers (Figure 1c).

Bones, specimen preparation and fracture creation

In the study, a total of 21 bovine femurs, which were readily available locally, were used. The specimens were stored at -16°C for at least 24 hours and then thawed to room temperature before testing. All bones were cleaned of soft tissue by the same orthopedist, and those of approximately the same length and weight were selected. On each femur, a standard Pauwels type 2 femoral neck fracture model with a 50° inclination relative to the horizontal plane was created using an angled cutting device approximately 2 cm medial to the greater trochanter. The osteotomy was performed with a precision band saw under fluoroscopy. A specially designed cutting guide was used to ensure repeatability of the 50° angle. The fracture plane was verified with a digital angle gauge and confirmed to be within $\pm 1^\circ$ tolerance radiographically. All specimens were positioned and fixed using the same alignment device to minimize variability during fixation and testing. Six femurs that were deformed or failed to achieve the desired angle while creating the Pauwels type 2 femoral fracture model with the angled cutting device, or that developed deformity during the implant application procedure, were excluded prior to biomechanical testing. These deformities included deviation from the required 50° osteotomy angle, cortical fractures during screw insertion, or slippage and loss of reduction during implant placement. These cases were excluded from the study because they disrupted the standard fracture model.

Biomechanical testing

Bovine femurs osteotomized at a 50° inclination were fixed using 3 different methods: DHS, CS, and MP (Figure 2), and the mechanical strength parameters of the fixation systems were compared.

Axial compression tests were performed, and force-displacement data were recorded. Compression tests were carried out on a Shimadzu AG-X 100 kN tensile testing machine (Figure 3) at a deformation speed of 2 mm/min, and instantaneous force-elongation data were recorded using Trapezium_X software. Maximum compressive force (Fmax), maximum elongation (Emax), maximum shear force (Fk), and maximum shear stress (τ_{max}) were calculated using force-displacement data and specimen dimensions (initial length (L0) and shear plane area (Ak)). For each sample group, 5 replicate tests were performed and the mean values were taken into account. Failure was defined as a sudden drop in the load value, rapid displacement along the fracture line, or the occurrence of a new fracture in the bone model. According to these results, statistical evaluation was made and results were obtained.

Statistical analysis

Data were analyzed using IBM SPSS Statistics 26 software package. Comparisons were made with ANOVA post hoc Tukey test and significance value was accepted ($P < .05$) for 95% CI.

Results

In the experimental study, compression tests were applied to specimen groups fixed by 3 different methods and the strength values of the fixing systems were evaluated comparatively. Compression tests were performed at a deformation rate of 2 mm/min and instantaneous force-displacement values were recorded. Using the obtained data and specimen dimensions (initial length (L0), shear plane area (Ak), maximum compression force (Fmax), maximum strain (Emax),

HIGHLIGHTS

- Cannulated screws (CS) fixation demonstrated the highest biomechanical stability in Pauwels type 2 femoral neck fractures.
- Cannulated screws fixation provided 58% higher maximum load-bearing capacity and superior shear force resistance than dynamic hip screw (DHS).
- Major plate (MP) fixation showed significantly lower mechanical strength and elongation compared to CS and DHS ($P < .05$).
- The shear stress distribution at the fracture line was most favorable with CS, while DHS and MP exhibited 36% and 45% weaker resistance, respectively.
- Findings suggest that CS, despite being less favored for Pauwels type 3 fractures, may be an effective and stable option for Pauwels type 2 fractures.

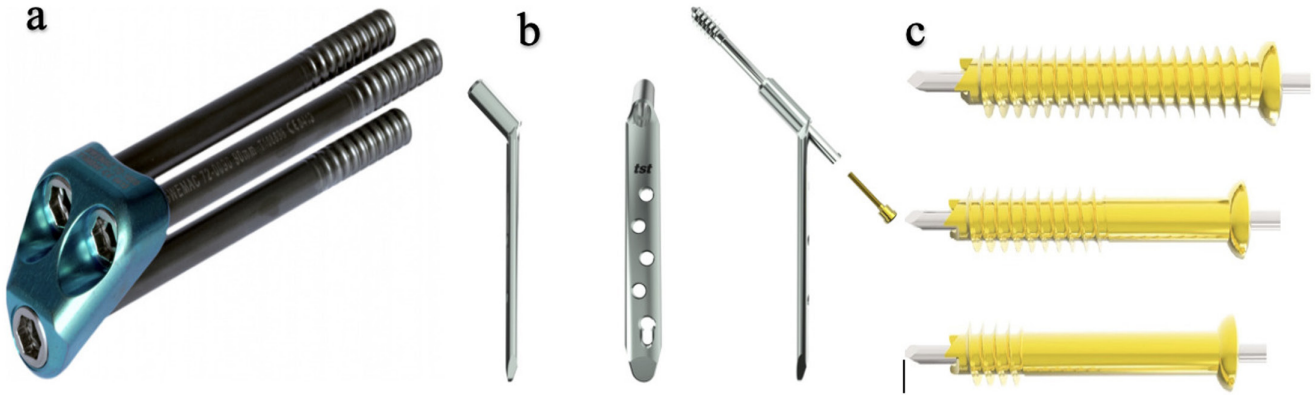


Figure 1. Major plate (a), Dynamic hip screw (b), Cannulated screw (c).

maximum shear force (F_k), and maximum shear stress (τ) values were calculated. For each specimen group, 5 repetitive tests were performed and the average values were taken into consideration. Figure 4 shows the compressive force–elongation curves obtained as a result of the compression tests of the specimen groups. The maximum compression force (F_{max}) of the DHS group specimens was measured as 4856.83 N on average and the maximum elongation (E_{max}) prior to failure was recorded as 32.12 mm (Figure 4). The CS group demonstrated a significantly higher maximum compression force (7688.20 N),

corresponding to a 58% increase compared with the DHS group ($P < .05$). Despite this increase, no significant difference was observed between the groups in terms of maximum elongation (Figure 4). In the MP group, a significant decrease was found in both maximum strength and elongation values compared to the other 2 groups ($P < .05$). Major plate group specimens showed an 18% decrease in maximum strength (3964 N) and a 45% decrease in maximum elongation (17.5 mm) compared to DHS group specimens. The mean values and standard deviation values obtained as a result of the maximum force and maximum elongation values measured for all sample groups are shown in Figure 4 and Table 1. As described earlier, the fracture lines were oriented at a 50° angle relative to the longitudinal axis of the

bone, and therefore the primary force responsible for deformation along the fracture plane is the shear component (F_{shear}). The value of the axial compression force (F_{max}) applied to the fracture line during compression tests is shown. Figure 5a shows a schematic representation of the effective compressive force on the fracture line and the shear force causing deformation. As can be seen from the figure, the effective shear force that causes deformation on the fracture line is calculated by multiplying the axial force by $\cos 40^\circ$ (Equation 1). However, before mechanical tests were carried out, dimensional measurements were made on the fracture lines to calculate the fracture plane areas, and if the fracture lines were considered as ellipses, the largest and smallest diameters R_1 and R_2 were measured (Figure 5b). Using the measured diameter values, the surface area of the fracture line was calculated using Equation 2.

$$Shear\ Force(F_k) = F_{max} \times \cos 40^\circ \quad (1)$$

$$Shear\ Area(A_k) = r_1 \times r_2 \times \pi \quad (2)$$

Comparing fixation systems solely on the basis of maximum compressive force may be misleading. Bone size variability may produce different F_{max} values even when fixation strength is identical. As it is known, the magnitude causing deformation is expressed by stress

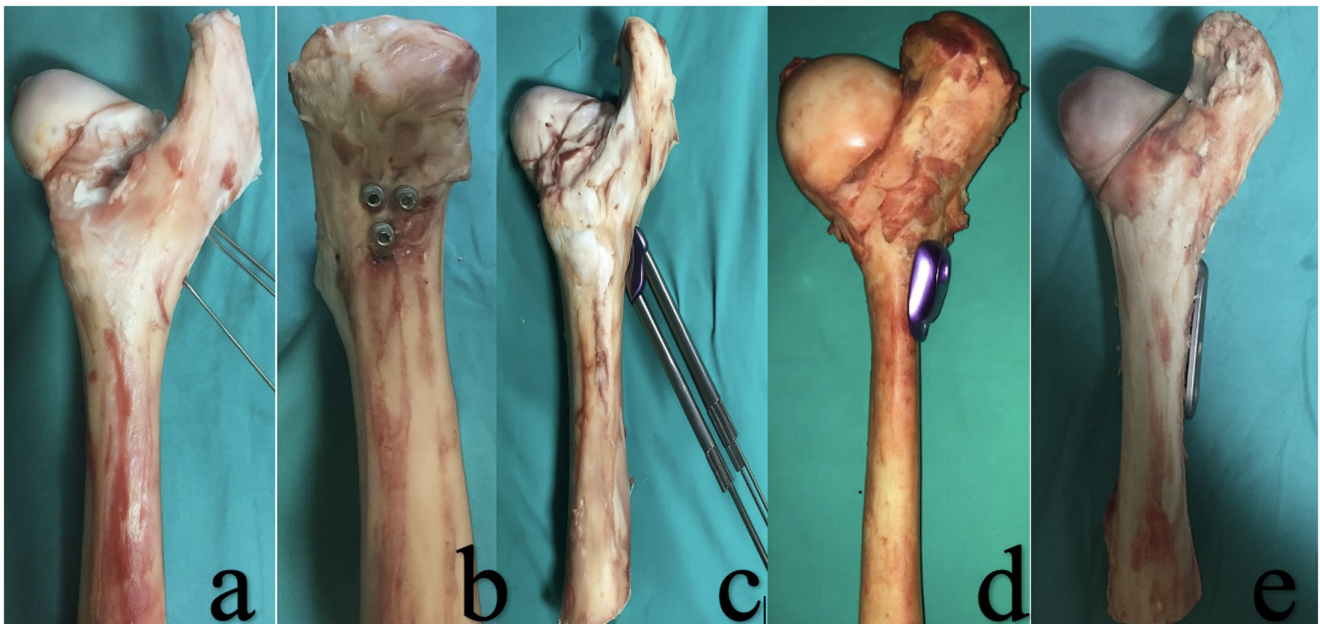


Figure 2. After creating a neck fracture in bovine femurs, the implants were fixed as follows: a, b: Cannulated screw - c, d: Major plate - e: Dynamic hip screw.



Figure 3. An axial compression test was performed on a bovine femur with a femoral neck fracture created and stabilized with dynamic hip screw using a Shimadzu AG-X 100 kN tensile testing machine.

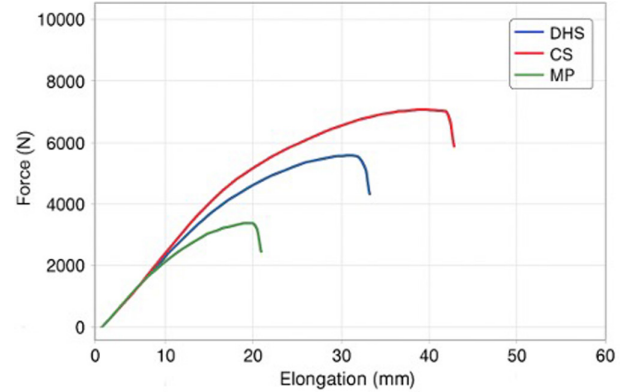


Figure 4. Mean force-elongation curves for 3 fixation methods: Dynamic hip screw (DHS), cannulated screws (CS), and major plate (MP). The curves represent the average force-elongation behavior obtained from 5 specimens in each group. Dynamic hip screw demonstrated moderate stiffness, CS showed the highest load-bearing capacity, and MP exhibited the lowest overall mechanical resistance.

and stress defines the effective force per unit area (F/A). Therefore, in 2 fixation systems with the same strength, the specimens with higher surface area will have larger F_{max} values. Therefore, in order to compare the strength of different fixation systems, it would be a better comparison to evaluate the shear stresses generated in the fracture planes. In order to calculate the shear stresses, the shear plane areas and the shear force values occurring in the shear plane need to be calculated. Equation 1 shows the shear forces generated at the fracture line by axial compression forces and Equation 2 shows how the shear plane areas are calculated. Equation 3 is the calculation of the maximum shear stress calculated from the shear force and shear plane areas. The F_k , A_k , and τ_{max} values obtained from all these calculations are summarized in Table 2.

$$\text{Shear Stress}(\tau) = \frac{F_k}{A_k} \quad (3)$$

When comparing the strength values of the fixation systems based on the shear stresses at the fracture line, the CS group demonstrated the highest shear stress capacity at 2.34 N/mm^2 . The DHS group showed a 36% decrease, reaching 1.50 N/mm^2 , while the MP group showed a 45% decrease, reaching 1.27 N/mm^2 . These findings indicate that CS fixation provides the greatest resistance to shear forces, whereas MP fixation offers the lowest strength among the 3 systems tested under axial compressive loading applied to a 50° fracture line (Table 1).

Discussion

The most important emphasis of the study is to biomechanically test the stability of fixation materials used in the surgical treatment of Pauwels type 2 FNF. Although there are similar studies in the literature comparing fixation materials in Pauwels type 3 FNF, to date, no study has directly compared DHS, CS, and MP in Pauwels type 2 fractures. The study is one of the few biomechanical investigations directly comparing different fixation methods for Pauwels type 2 FNF, which are difficult to treat and associated with significant morbidity in young patients. In this study, the cannulated screw construct exhibited the highest biomechanical strength. It is concluded that CS materials, which are not recommended in the literature because they do not provide sufficient stability in Pauwels type 3 FNF, may be a safe treatment option in relatively more stable Pauwels type 2 FNF. These findings highlight the critical role of fracture inclination in determining the optimal implant. While CS constructs may be insufficient for highly vertical (Pauwels type 3) fractures, their superior

Table 1. Statistical information of different fixation materials used in the study

	N	^a DHS x ± sd	^b CS x ± sd	^c MP x ± sd	Total x ± sd	P	Post hoc Tukey
F _{max}	5	4856.83 ± 828.34	7688.20 ± 1789.83	3964.00 ± 1187.10	5503.01 ± 2052.89	.002	b/a; b/c
F _k	5	3720.33 ± 634.51	5889.16 ± 1371.01	3036.42 ± 909.32	4215.31 ± 1572.52	.002	b/a; b/c
Shear stress N/mm ²	5	1.50 ± 0.16	2.34 ± 0.47	1.27 ± 0.27	1.70 ± 0.56	.001	b/a; b/c

The superior performance of the CS group reflects axial loading conditions in a bovine model and may differ under torsional or cyclic loading or in human cadaveric bone CS, cannulated screws; DHS, dynamic hip screw; MP, major plate.

performance in type 2 fractures suggests that lower shear angles allow more effective load sharing along the screw axis. The study is important in terms of guiding future biomechanical experiments with cadaveric bones.

It has been reported that fracture type, bone quality, patient age, stability of reduction, position of the implant in the femoral head, and the type of implant used are effective for the fixation stability of FNF.¹³ Despite many studies, there are very few studies describing the factors that play a role in implant stability and the relationship between these factors.¹⁴

Dynamic hip screw technique has been used in the surgical treatment of hip fractures since the 1960s and it is still a current stabilization method even though surgical techniques have been improved and different fixation methods have been used.¹⁵ The advantage of this method is that the screw can be sent up to the subchondral area in the femoral head and provides uniform compression on the fracture line and increases stability.¹⁶ In stable fractures, the results are often successful regardless of the fixation method used, as the reduction is easy, the medial support is good and thus the compressive forces pass through the medial part of the femoral neck.¹⁷ In the stabilization of hip fractures with the DHS method, implant failure has been shown at different rates between 5.3% and 23%.^{14,18}

Cannulated screws fixation is often preferred in young patients with good bone quality and minimally displaced fractures due to its shorter operative time and preservation of the fracture hematoma.¹⁹ As a method of application, a diamond configuration with 4 screws, an equilateral triangle configuration with 3 screws and a distal base, or an inverted equilateral triangle design have been described. In the experiments, it was reported that 3 screws were biomechanically more advantageous than 2 screws, but the fourth screw did not contribute to stability.²⁰ In the experimental study, a triangular arrangement was used proximally at the base in the CS group.

Contoured locking compression plates have been proposed for fixation of FNF. Compared to other implants, they have shown

biomechanical advantages in terms of initial stability (i.e., structural stiffness) of fracture fixation. In the study, all specimens in the CS group demonstrated higher load-bearing capacity and showed an increase of 58% compared to the DHS group. Despite this increase in strength, there was no significant difference in the maximum elongation between the 2 groups. In a study performed in Pauwels type 3 fractures with axial loading, DHS was shown to have significantly better strength than CS.²¹ In the study, the CS group demonstrated the highest mechanical strength, whereas the MP group showed the lowest. In another study comparing cannulated screw with DHS, the CS group maintained a significantly lower mean peak force. The CS group showed a lower ultimate load until failure.²² Another study showed no difference between the 2 methods.²³ In the experimental study, the maximum compressive force (F_{max}) was found to be approximately 4856.83 N in the DHS group and the maximum elongation before failure, E_{max}, was reported to be 32.12 mm. In a study evaluating 3 groups in the literature, the plate group showed the least loss of fracture reduction in the early stages of loading, as well as good results in terms of reduction loss and strength characteristics.²⁴ The study recommended cautious use of CS in the treatment of unstable vertical FNFx, such as those with extensive posterior fragmentation, because of the possibility of loss of fracture reduction as well as lower stiffness and loss of reduction.²⁵ Rupprecht et al biomechanically compared DHS, intertan nail, and 3 CS with inverted triangular configuration with a force of 1400 N at 2 Hz in the stabilization of standard Pauwels type 3 unstable transcervical FNFx in human cadaver femur and showed that fixation with nail reached higher fracture load compared to other techniques.²⁶ In the same study, a failure rate of approximately 12.5% in the PFN group, almost 50% in the DHS group, and 75% in the CS group was reported in the cyclic loading aimed at 10000 cycles.²⁶ In the experimental study, in the fixation of Pauwels type 2 transcervical fractures in bovine femurs, DHS had higher fracture loads after CS, while stabilization with MP had significantly lower fracture loads and fixation durability compared to other techniques. A review of the literature shows that most biomechanical studies have focused on Pauwels type 3 fractures and the results of DHS and plate fixation methods are generally better than CS fixation.²⁷ In the study, axial loading tests of the CS fixation method in relatively more stable Pauwels type 2 FNFx showed very good results.

In previous studies on Pauwels type 3 fractures, it has been reported that CS provides lower stability compared to DHS or medial plates.^{9,28} We confirm the change. Thank you for the correction. However, the findings of the present study demonstrate that CS fixation is biomechanically superior in Pauwels type 2 fractures. It is believed that this difference is due to the lower shear moment and reduced vertical instability in type 2 fractures, which allows for a more balanced distribution of load along the screw axis.

Previous studies have highlighted the influence of screw configuration on fixation stability.¹¹ In this study, the superior performance of CS in Pauwels type 2 fractures compared to type 3 fractures may be due to the optimization of screw angles and more effective load transfer along the fracture line. Clinically, implant selection should be based on factors

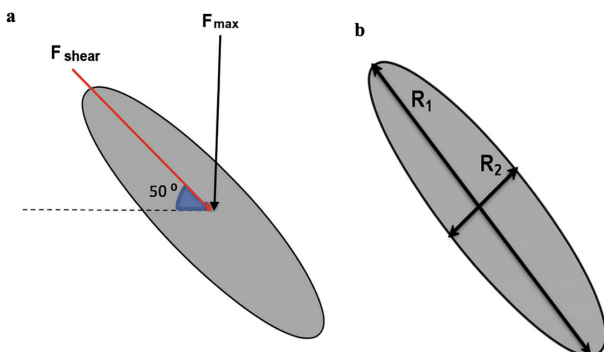


Figure 5. Calculation of shear force acting on the fracture plane (a). Measurement of fracture surface dimensions (R1 and R2) used to determine shear plane area (b).

Table 2. Maximum force (Fmax) and shear stress values (mean $\pm$ SD) calculated according to fracture line surface area

Fixation type	Fmax (N)	Fk (N)	R1 (mm)	R2 (mm)	Ak (mm ²)	Shear Stress (N/mm ²)	% Difference vs. MP
DHS	4856.8 $\pm$ 828.3	3720.3 $\pm$ 634.5	76.0 $\pm$ 6.5	41.6 $\pm$ 2.7	2479.3 $\pm$ 228.3	1.50 $\pm$ 0.17	+18.1
CS	7688.2 $\pm$ 1789.8	5889.2 $\pm$ 1371.0	76.2 $\pm$ 6.5	42.0 $\pm$ 2.6	2513.6 $\pm$ 287.4	2.34 $\pm$ 0.47	+84.3
MP	3964.0 $\pm$ 1187.1	3036.4 $\pm$ 909.3	74.2 $\pm$ 3.4	40.6 $\pm$ 3.6	2366.1 $\pm$ 244.2	1.27 $\pm$ 0.27	—

CS, cannulated screws; DHS, dynamic hip screw; MP, major plate.

such as fracture inclination and bone quality. Cannulated screws fixation may be an appropriate option in younger patients with good bone quality and less vertical (type 2) fractures. In contrast, DHS or medial plates should be preferred in more vertical or osteoporotic fractures (type 3). These findings provide a biomechanical basis for the individualization of fixation methods according to fracture morphology.

Limitations and strengths

This study has several limitations. First, only 5 specimens were used in each group. Although this number is comparable to similar biomechanical investigations, it may limit the statistical power of the findings. Second, bovine femurs were used instead of human cadaveric bones. Although bovine bones provide homogeneous bone quality and geometric consistency and are therefore frequently preferred in biomechanical experiments, they differ from human femurs in terms of bone mineral density, trabecular microstructure, and cortical thickness. These structural differences may affect absolute load-bearing capacity and deformation behavior. However, since all fixation methods were tested under identical experimental conditions, the validity of relative comparisons between the methods was preserved. Since bovine bone differs from human cadaver bone in terms of mineral density and microarchitecture, the absolute force values obtained in this study (e.g., 7688 N in CS) may not directly correspond to human physiological conditions; therefore, relative comparisons between fixation methods provide a more meaningful interpretation.

Third, the experimental loading protocol was limited to axial compression. Axial testing provides valuable information on stiffness and failure characteristics under compressive loads; however, it does not fully replicate the complex physiological conditions of the hip joint, where torsional, bending, and repetitive (cyclic) forces are also present. Therefore, future studies are recommended to incorporate combined and cyclic loading protocols to better simulate physiological conditions. Furthermore, because this study was conducted exclusively on young and intact bovine femurs, the stability of the fixation methods in osteoporotic bone could not be evaluated. Another limitation is that the tests were performed in vitro on inanimate specimens lacking soft tissues, which may influence the biomechanical response.

Despite these limitations, the study has several strengths. All experiments were conducted by an experienced research team under identical laboratory conditions and with the same testing equipment. The use of bovine femurs of similar age and environmental background enhanced inter-sample biomechanical consistency. Another strength is that the comparison of different fixation methods was based on the calculation of shear stresses across the fracture planes. Dimensional measurements of the osteotomy line and determination of the surface area allowed objective evaluation of the shear strength of each fixation technique, thereby enabling a biomechanically sound comparison among the methods.

In this study, 3 different fixation methods were biomechanically compared in Pauwels type 2 FNF created on bovine femur models. The results demonstrated that CS provided the highest biomechanical

stability, followed by the DHS and the MP. Fixation with CS showed significantly higher maximum fracture load and lower displacement values compared to DHS ($P < .05$). Major plate fixation was found to be statistically weaker than the other fixation methods ($P < .05$).

These findings suggest that CS may provide sufficient stability, particularly in less vertical Pauwels type 2 fractures and in patients with good bone quality. However, due to methodological limitations such as the small sample size, the use of a bovine bone model, and testing under only axial loading conditions, these results should not be directly generalized to clinical practice. The study provides a biomechanical basis for implant selection in specific fracture types, and further research using human cadaveric femurs with torsional and cyclic loading tests is warranted to validate these findings.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Artificial Intelligence Usage Statement: The authors declared that no Artificial Intelligence tool was used in the preparation of the manuscript.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee Firat University (Approval no: 2021/05-04, Date: 08.04.2021).

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References

- Bhandari M, Swiontkowski M. Management of acute hip fracture. *N Engl J Med*. 2017;377(21):2053-2062. [\[CrossRef\]](#)
- Wilson JM, Jones CA, Holmes JS, et al. Fixation vs arthroplasty for femoral neck fracture in patients aged 40-59 years: A propensity-score-matched analysis. *Arthroplast Today*. 2022;14:175-182. [\[CrossRef\]](#)
- Kang JS, Moon KH, Shin JS, et al. Clinical results of internal fixation of subcapital femoral neck fractures. *Clin Orthop Surg*. 2016;8(2):146-152. [\[CrossRef\]](#)
- Slobogean GP, Sprague SA, Scott T, et al. Complications following young femoral neck fractures. *Injury*. 2015;46(3):484-491. [\[CrossRef\]](#)
- Slobogean GP, Sprague S, Bzovsky S, et al. Fixation using alternative implants for the treatment of hip fractures (FAITH-2): the clinical outcomes of a multicenter 2 $\times$ 2 factorial randomized controlled pilot trial in young femoral neck fracture patients. *J Orthop Trauma*. 2020;34(10):524-532. [\[CrossRef\]](#)
- Zhou XQ, Li ZQ, Xu RJ, et al. Comparison of early clinical results for femoral neck system and cannulated screws in the treatment of unstable femoral neck fractures. *Orthop Surg*. 2021;13(6):1802-1809. [\[CrossRef\]](#)
- Nandi S. Revisiting Pauwels' classification of femoral neck fractures. *World J Orthop*. 2021;12(11):811-815. [\[CrossRef\]](#)
- McGarry L, Rotaru J, Gunaratne R, et al. Medial buttress plate use in neck of femur fracture fixations: a systematic review. *Injury*. 2025;56(2):112160. [\[CrossRef\]](#)
- Onder Y, Bulut T, Eroglu ON, et al. Biomechanical comparison of locking femoral neck plate versus cannulated screws with or without a medial buttress plate in Pauwels type 3 femoral neck fractures. *Acta Orthop Traumatol Turc*. 2024;58(6):313-317. [\[CrossRef\]](#)

10. Tang Z, Zhang Y, Huang S, et al. Biomechanical study of a biplanar double support screw (BDSF) technique based on Pauwels angle in femoral neck fractures: finite element analysis. *Front Bioeng Biotechnol.* 2024;12:1358181. [\[CrossRef\]](#)
11. Verim Ö. Biomechanical evaluation of cannulated screw optimization for stabilization of pauwels type femoral neck fractures. *Appl Sci.* 2024;14(7):2807. [\[CrossRef\]](#)
12. Mansur H, Alvarez R, Freitas A, et al. Biomechanical analysis of femoral neck fracture fixation in synthetic bone. *Acta Ortop Bras.* 2018;26(3):162-165. [\[CrossRef\]](#)
13. Stoffel K, Zderic I, Gras F, et al. Biomechanical evaluation of the femoral neck system in unstable pauwels III femoral neck fractures: A comparison with the dynamic hip screw and cannulated screws. *J Orthop Trauma.* 2017;31(3):131-137. [\[CrossRef\]](#)
14. Panteli M, Rodham P, Giannoudis PV. Biomechanical rationale for implant choices in femoral neck fracture fixation in the non-elderly. *Injury.* 2015;46(3):445-452. [\[CrossRef\]](#)
15. Schwartzmann CR, Jacobus LS, Spinelli F, et al. Dynamic hip screw for the treatment of femoral neck fractures: a prospective study with 96 patients. *ISRN Orthop.* 2014;2014:257871. [\[CrossRef\]](#)
16. Chang JZ, Xiao YP, Li L, et al. The efficacy of dynamic compression locking system vs. dynamic hip screw in the treatment of femoral neck fractures: a comparative study. *BMC Musculoskelet Disord.* 2022;23(1):661. [\[CrossRef\]](#)
17. Boraiah S, Paul O, Hammoud S, et al. Predictable healing of femoral neck fractures treated with intraoperative compression and length-stable implants. *J Trauma.* 2010;69(1):142-147. [\[CrossRef\]](#)
18. Zhang Y, Tian L, Yan Y, et al. Biomechanical evaluation of the expansive cannulated screw for fixation of femoral neck fractures. *Injury.* 2011;42(11):1372-1376. [\[CrossRef\]](#)
19. Singh DM, Sonkar DD, Verma DR, et al. Comparison of the functional outcome of DHS versus cannulated cancellous screws in pauwels type II and III fracture neck femur in young adults. *Int J Orthop Sci.* 2017;3(2h):745-749. [\[CrossRef\]](#)
20. Zhang RY, Li JT, Zhao JX, et al. Comparison of oblique triangular configuration and inverted equilateral triangular configuration of three cannulated screws in treating unstable femoral neck fracture: a finite element analysis. *Injury.* 2022;53(2):353-361. [\[CrossRef\]](#)
21. Li Z, Zhang X, Li Z, et al. Comparative study of Pauwels type III femoral neck fractures managed by short dynamic hip screw with fibula bone graft or cannulated screws in young adults. *Ann Transl Med.* 2020;8(11):681. [\[CrossRef\]](#)
22. Siavashi B, Aalirezai A, Moosavi M, et al. A comparative study between multiple cannulated screws and dynamic hip screw for fixation of femoral neck fracture in adults. *Int Orthop.* 2015;39(10):2069-2071. [\[CrossRef\]](#)
23. Biz C, Berizzi A, Crimi A, et al. Management and treatment of femoral neck stress fractures in recreational runners: a report of four cases and review of the literature. *Acta Biomed.* 2017;88(4S):96-106. [\[CrossRef\]](#)
24. Aminian A, Gao F, Fedoriw WW, et al. Vertically oriented femoral neck fractures: mechanical analysis of four fixation techniques. *J Orthop Trauma.* 2007;21(8):544-548. [\[CrossRef\]](#)
25. Bliven E, Sandriesser S, Augat P, et al. Biomechanical evaluation of locked plating fixation for unstable femoral neck fractures. *Bone Joint Res.* 2020;9(6):314-321. [\[CrossRef\]](#)
26. Rupprecht M, Grossterlinden L, Ruecker AH, et al. A comparative biomechanical analysis of fixation devices for unstable femoral neck fractures: the Intertan versus cannulated screws or a dynamic hip screw. *J Trauma.* 2011;71(3):625-634. [\[CrossRef\]](#)
27. Cha YH, Yoo JI, Hwang SY, et al. Biomechanical evaluation of internal fixation of pauwels Type III femoral neck fractures: A systematic review of various fixation methods. *Clin Orthop Surg.* 2019;11(1):1-14. [\[CrossRef\]](#)
28. Nowotarski PJ, Ervin B, Weatherby B, Pettit J, Goulet R, Norris B. Biomechanical analysis of a novel femoral neck locking plate for treatment of vertical shear Pauwel's type C femoral neck fractures. *Injury.* 2012;43(6):802-806. [\[CrossRef\]](#)