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Research Article

Biomechanical comparison of fixation methods on third-generation femoral composite bone models in Pauwels type 3 femoral neck fractures: Contribution of the medial buttress plate to fixation

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ABSTRACT

Objective: To compare the use of cannulated screws in an inverted triangular configuration, medial buttress plates, and the combination of these 2 fixation methods in the treatment of Pauwels type 3 femoral neck fractures.

Methods: Twenty-eight anatomical composite third-generation femoral bone models were divided into 4 groups. The control group (group 1) was formed with 7 third-generation intact bone models. The fracture model was created with a 70° cutting block to fit 21 Pauwels type 3 fracture configurations. Seven models were fixed with an isolated 3.5 mm one-third semi-tubular medial buttress plate (group 2), 7 were fixed in an inverted triangular configuration with 6.5 mm cannulated screws (group 3), and 7 were fixed using a combination of 6.5 mm cannulated screws and a medial buttress plate (group 4). Cyclic loading was applied using axial forces ranging from 60 N to 600 N and moments ranging from 0.7 Nm to 7.0 Nm for 500 cycles. Once the cyclic loading stage was completed, the loads were removed from the system, and the quasi-static loading stage was employed to determine the stiffness and failure forces of the system under both axial and torsional forces. Quasi-static tests were performed with an axial speed of 1.8 mm/min and a torsional speed of 4.5°/min. The biomechanical properties of all groups were examined in terms of axial stiffness, torsional stiffness, and maximum axial force parameters.

Results: The stiffness values of groups 1, 2, 3, and 4 were 303 ± 35.8 N/mm, 159.6 ± 25 N/mm, 232 ± 35.9 N/mm, and 366.9 ± 58 N/mm, respectively, under axial forces ($P < .01$); 2172.7 ± 252.1 Nmm/°, 1225.3 ± 238.6 Nmm/°, 2123 ± 359.4 Nmm/°, and 2721.85 ± 304 Nmm/°, respectively, under torsional moments ($P < .01$); and 2072.1 ± 256.1 N, 1379.9 ± 290.6 N, 2099.1 ± 454.2 N, and 2648.4 ± 364.6 N, respectively, under the maximum force ($P < .01$).

Conclusion: This study showed that in the fixation of Pauwels type 3 fractures formed on third-generation bone models, the utilization of half-thread cannulated screws in an inverted triangle configuration, along with a medial buttress plate, provided stronger fixation compared to the remaining implant groups and the control group. According to the evaluation of the parameters, the isolated application of a medial buttress plate had poorer biomechanical properties than other fixation methods.

Introduction

Hip fractures constitute a significant health problem in the elderly population. Given the projected rise in life expectancy and the subsequent growth of the elderly population, the global incidence of hip fractures is expected to increase from 1.26 million in 1990 to 4.5 million by 2050.[1] Today, hip fractures affect 18% of women and 6% of men worldwide.[1] Femoral neck fractures account for 60% of these fractures and occur primarily in the elderly.[2] Pauwels type 3 fractures, which occur after high-energy injuries in the young adult group, are characterized by high shear forces at the fracture line and are associated with a high postoperative implant failure rate.[3,4] In the young adult group, the femoral head should be preserved, and open or closed reduction and osteosynthesis should be prioritized. There is currently no universally accepted gold standard method for the fixation of this type of fracture.[4] In the context of Pauwels type 3 fractures, it has been observed that despite achieving excellent fracture reduction and stable fixation, osteonecrosis of the femoral head can occur at a rate ranging from 25% to 80%.[4] To reduce the complication rate in the treatment of Pauwels type 3 femoral neck fractures and increase the success of treatment in clinical practice, researchers have conducted investigations in both preclinical and clinical settings.[3,4]

The decision to include isolated medial buttress plate fixation in the current study was made in accordance with the findings of Mir and Collinge.[5] The incorporation of this technique into our study was motivated by its several advantages, including direct access to the fracture with open reduction, and the potential to resist vertical shearing forces in Pauwels type 3 fractures.[5] Furthermore, considering that a medial buttress plate has recently been used in addition to existing methods for such fractures, its isolated use may provide an alternative method for this type of fracture. The current literature contains publications on the utilization of a medial buttress plate and

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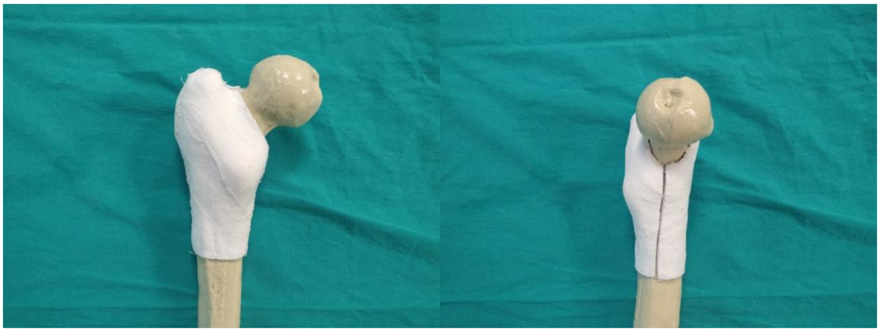

Figure 1. Appearance of the femoral bone model and the 70° guided cutting block used in the study.

cannulated screw fixation in the osteosynthesis of femoral neck fractures.[6-9] However, in one of these studies in which a buttress plate was applied to the medial femoral neck and cannulated screw fixation was used in vertical femoral neck fracture models, only axial stiffness was evaluated.[10] Our study differs from previous research in terms of the inclusion of a control group that did not undergo implantation, as well as an isolated medial buttress plate. We conducted our study using third-generation femur models with the aim of contributing to the literature by analyzing data. We hypothesize that the use of a medial buttress plate alone or in combination with other methods provides a biomechanical advantage in the treatment of patients with Pauwels type 3 femoral neck fractures, a condition characterized by vertical instability.

Material and methods

Ethics committee approval was not necessary due to the biomechanical nature of the study. The academic committee of the University of Health Sciences Department of Orthopedics and Traumatology provided clearance for the study (date: November 1, 2019, decision no. 2019/08). Twenty-eight third-generation composite anatomical femur models (Model: FMR-01 New Third-Generation Composite Left Femur; Selbones Research Laboratory, Kayseri, Turkey) were used as a single type in this study.

The bone models were divided into 4 groups. A fracture model was created by cutting 21 implanted bones with the prepared cutting block at an angle of 70° to fit the Pauwels type 3 fracture model (Figure 1). The control group (group 1) was formed with 7 bone models without cutting or implantation. A fracture model was created with a 70° angled cutting block to match the fracture configuration of Pauwels type 3 for the 21 implanted bone models. Seven of these models were fixed with an isolated 3.5 mm one-third semi-tubular medial buttress plate (group 2), 7 were fixed in an inverted triangular configuration with isolated 6.5 mm partially threaded cannulated screws (group 3), and the remaining 7 were fixed with the combined use of 6.5 mm semi-threaded cannulated screws and a medial buttress plate (group 4) (Figure 2).

HIGHLIGHTS

- Pauwels type 3 femoral neck fractures are vertically unstable fractures, for which standard fixation methods may not provide sufficient stability during union.
- The use of a buttress plate on the medial femoral neck in addition to standard fixation in vertically unstable fractures significantly increases stability.
- In vertically unstable fractures, the use of an isolated buttress plate on the medial side of the femoral neck does not seem to provide adequate fixation.

All groups included in the study were subjected to axial and torsional forces, and their biomechanical properties were examined in terms of axial stiffness, torsional stiffness, and ultimate axial compression force parameters (Figure 3). Biomechanical testing was performed using the MTS 858 Mini Bionix II device.

Biomechanical tests

The shaft end of the specimens was fixed in a polyvinyl chloride pipe and stabilized with polyester resin. The head of the specimens was fixed with a specifically designed aluminum apparatus that completely enclosed the femoral head. The inner shape of this apparatus was prepared as a mold to fit the heads of the femoral specimens (Figure 3).

The tests were performed using a universal testing machine (MTS 858 Mini Bionix II) at the Strength of Materials & Biomechanics Laboratory of Istanbul Technical University. The prepared specimens were positioned in a steel pot that was fixed to a vise. An axial-torsional load transducer was used to establish the natural position of the femur, characterized by a 7° valgus angle. The femoral head of the bone was fixed to the upper jaw of the testing device using the aforementioned apparatus (Figure 3).

The applied axial force and moment values were gathered continuously from the transducer (MTS Axial-Torsional Load Transducer (25 000 N/250 Nm), S/N: 10182414). At the same time, the displacements and angles were measured using a displacement transducer (MTS LVDT Transducer, S/N: 10188729) and an angle transducer (MTS ADT Transducer, S/N: C11382).

The biomechanical tests started with a set of cyclic loading to eliminate the gaps and instabilities in the system that could occur due to fixation. Cyclic loading was only used for the stability of the test system and did not include any physiological loading. In the cyclic loading stage, an axial compressive force was simultaneously applied with a moment at a 2.5 Hz loading frequency. The cyclic loading was applied with an axial force of 60 N to 600 N and a moment of 0.7 Nm to 7.0 Nm during 500 cycles. Once the cyclic loading stage was completed, the loads were removed from the system, and the quasi-static loading stage was started to determine the stiffness and failure force of the system under both axial and torsional forces. Compression and torsion were applied from the bone's mechanical axis due to the bone's in vitro position. Quasi-static tests were performed with an axial speed of 1.8 mm/min and a torsional speed of 4.5°/min.

The failure criteria were evaluated manually and included screw pullout, significant separation along the cut line, deformation or breakage of the plate, or fracture/crack in any part of the specimen. In

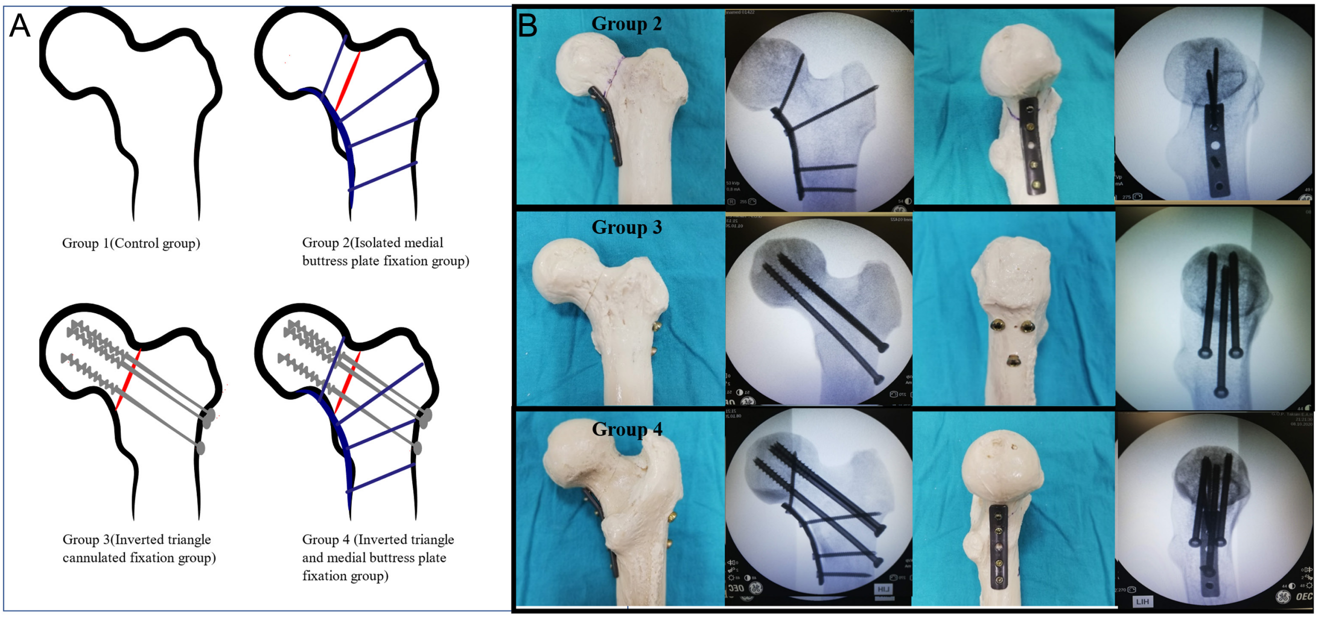

Figure 2. (A) Schematic illustrations of the groups in our study. (B) Macroscopic and x-ray images of groups 2, 3, and 4.

the event that breakage was observed in the specimen due to screw pullout or movement along the fracture line was detected, the test was terminated. Our focus was on the investigation of the behavior of the bone models during the test. Therefore, if any visual deformation was observed, we terminated the test. In the absence of any observable visual deformation, the test continued until the specimen finally broke. Following the completion of the tests, the results graphs were examined one by one and compared using test notes. By employing this method, we were able to easily identify the breaking point. We also checked the visual component where necessary.

Using the raw data, axial stiffness, torsional stiffness, and maximum axial force values were calculated with the MATLAB 2019 software. Stiffness refers to how a component resists elastic deformation when a load is applied. Axial stiffness is the internal resistance to the upcoming axial load on any material. When the load acts axially on any material, the material reacts to this upcoming load, and the resistance to this load is known as axial stiffness. Torsional stiffness is the ability of an object to resist twisting in response to an externally applied torque. In the mechanics of materials, torsional stiffness is the resistance to a material's angular deformation. The amount of strain determines the material's resistance to the external load applied. Therefore, when the relationship between the external load applied to the material and the strain is depicted graphically, the slope in the graph's linear region represents the magnitude of the resistance. Using this method, we also measured strains under torsion and axial loading. For each specimen, we plotted the external load (axial and torsional forces) and the corresponding angle and displacement graphs.

For each graph, the steepness of the chart in the linear region provided the material's resistance to the load. We used linear regression on the linear part of the force-strain curve and the torque-strain curve to calculate axial stiffness and torsional stiffness, respectively. The linear part showed slight differences according to the plots of the specimens. The graphs obtained from the test results were drawn using Microsoft Excel. When the graphs were examined individually, it was determined that the regions between 10% and 40% were suitable for the linear region. However, when examining the material behavior of the specimens, there were slight differences in the force-strain graphs.

The purpose of cyclic loading stages was to eliminate any gaps and instabilities in the test system that could occur due to fixation (Figure 4). However, neither the 600 N nor 7 Nm loads were near the failure loads (these values were chosen from a set of pretest groups and always remained within elastic limits). Therefore, they did not impact the specimens' stiffness or failure loads.

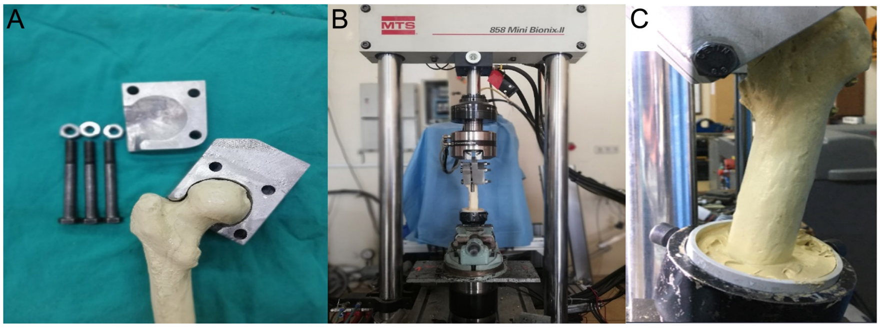

Figure 3. (A) Aluminum apparatus arranged in accordance with the femoral head. (B) 858 Mini Bionix II device used for biomechanical testing. (C) Orientation of models using a steel pot in single leg stance position.

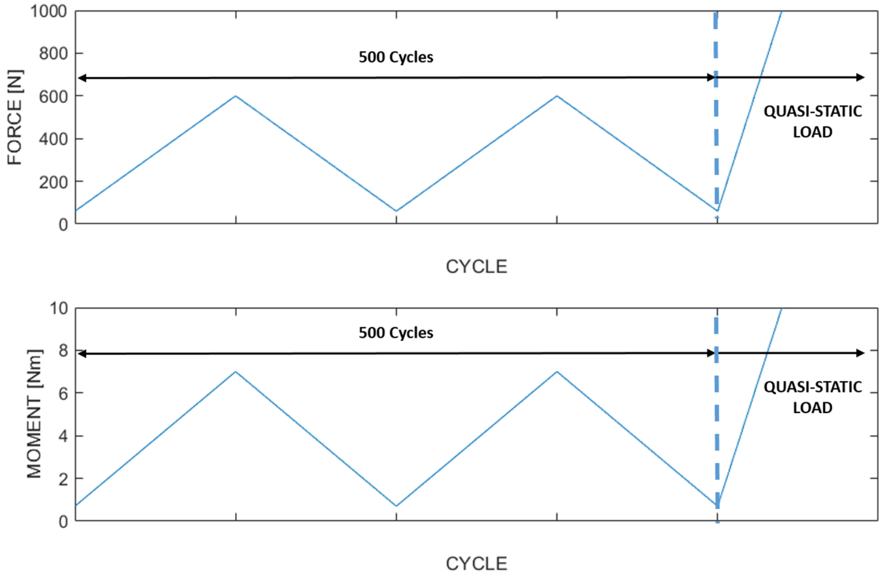

Figure 4. Schematic moment–force/cycles graph.

As in the gait analysis described by Gervais et al,[11] we employed a combined approach for loading rather than applying individual loads, mirroring the manner in which this occurs in daily life.

Statistical analysis

Statistical analyses of the data were conducted using the Statistical Package for the Social Sciences Statistics, version 22.0 (IBM SPSS Corp.; Armonk, NY, USA). Descriptive analyses were presented as means and standard deviations. The distribution of the data was evaluated using the Shapiro–Wilk test. The results were analyzed using one-way analysis of variance and Tukey's post hoc test. A *P*-value of <.05 was considered statistically significant.

Results

The stiffness values of groups 1, 2, 3, and 4 were 303 ± 35.8 N/mm, 159.6 ± 25 N/mm, 232 ± 35.9 N/mm, and 366.9 ± 58 N/mm, respectively, under axial forces ($P < .01$); 2172.7 ± 252.1 Nmm/°, 1225.3 ± 238.6 Nmm/°, 2123 ± 359.4 Nmm/°, and 2721.85 ± 304 Nmm/°, respectively, under torsional moments ($P < .01$); and 2072.1 ± 256.1 N, 1379.9 ± 290.6 N, 2099.1 ± 454.2 N, and 2648.4 ± 364.6 N, respectively, under the maximum force ($P < .01$). The detailed data on axial stiffness, torsional stiffness, and maximum axial force causing femoral neck fractures in all groups are given in Tables 1, 2, 3, and 4.

Axial stiffness

In terms of axial stiffness, the fixation results of group 4 were significantly better than those of the remaining groups ($P < .0001$). When group 4 was compared to group 1, the fixation in group 4 exhibited significantly superior axial stiffness before fracture ($P < .05$). Groups 2 and 3 (inverted triangle) offered statistically weaker fixation compared to group 1 (control group) ($P < .05$). Group 3 (inverted triangle) was proven to be statistically stronger than group 2 (medial plate) ($P < .05$). Lastly, group 2 provided weaker fixation than the remaining groups in terms of axial stiffness ($P < .01$) (Table 5).

Table 1. Biomechanical end-of-test data of the control group (group 1)

Specimen number	1	2	3	4	5	6	7
Axial stiffness (N/mm)	260	317	362	261	316	292	313
Torsional stiffness (Nmm/°)	2028	1984	2407	1979	2156	2024	2631
Maximum axial force (N)	1983	2123	2567	1803	1933	1898	2198

Torsional stiffness

In relation to torsional stiffness, the fixation results of group 4 were significantly better than those of the remaining groups ($P < .0001$).

Table 2. Biomechanical end-of-test data of the isolated medial buttress plate fixation method (group 2)

Specimen number	1	2	3	4	5	6	7
Axial stiffness (N/mm)	191	189	149	144	175	129	140
Torsional stiffness (Nmm/°)	1254	1116	1430	1439	1456	826	1056
Maximum axial force (N)	1400	1270	1198	1812	1745	1154	1080

Table 3. Biomechanical end-of-test data of the inverted triangle configuration group (group 3)

Specimen number	1	2	3	4	5	6	7
Axial stiffness (N/mm)	296	188	242	219	255	205	219
Torsional stiffness (Nmm/°)	2357	1944	2444	1413	2394	2207	2102
Maximum axial force (N)	2402	1430	1932	1722	2318	2098	2792

Table 4. Biomechanical end-of-test data of the inverted triangle configuration + medial buttress plate group (group 4)

Specimen number	1	2	3	4	5	6	7
Axial stiffness (N/mm)	410	373	411	250	393	334	397
Torsional stiffness (Nmm/°)	3257	2701	2703	2357	2907	2406	2722
Maximum axial force (N)	2695	2270	2985	2589	2388	3263	2349

Table 5. Comparison of the groups with regard to biomechanical properties

	Group 1 (mean ± SD)	Group 2 (mean ± SD)	Group 3 (mean ± SD)	Group 4 (mean ± SD)	*P*
Axial stiffness (N/mm)	303 ± 36	159.6 ± 25	232 ± 36	366.9 ± 58	<.0001
Torsional stiffness (Nmm/°)	2172.7 ± 252.1	1225.3 ± 238.6	2123 ± 359.4	2721.85 ± 304	<.0001
Maximum axial force (N)	2072.1 ± 256.1–	1379.9 ± 290.6	2099.1 ± 454.2	2648.42 ± 364.6	<.0001

Group 1: control group, group 2: a 3.5 mm, one-third semi-tubular medial buttress plate alone, group 3: inverted triangular configuration with 6.5 mm cannulated screws, group 4: combined use of 6.5 mm cannulated screws and a medial buttress plate.

The fixation in group 4 was statistically stronger than that observed in the control group ($P < .01$), but there was no statistically significant difference between groups 3 and 1 ($P > .05$). The fixation in group 3 provided a similar level of torsional stiffness to group 1. Group 2 provided weaker fixation than the remaining groups in terms of torsional stiffness ($P < .01$) (Table 5).

Maximum axial force

Upon analyzing the results of maximum axial force, it was found that group 4 exhibited significant superiority over the remaining groups ($P < .0001$). The fixation in group 4 was significantly stronger than that observed in group 1 ($P < .05$). There was also a statistically significant difference between groups 3 and 1 ($P > .05$). Group 3 provided as strong a fixation as group 1 under maximum axial force. Group 2 provided inadequate fixation in terms of maximum axial force compared to group 1 ($P < .01$). Lastly, group 2 provided weaker fixation than the remaining groups under maximum axial force ($P < .01$) (Table 5).

Discussion

In our study, a vertically unstable Pauwels type 3 femoral neck fracture was created using third-generation proximal femur bone models. Osteosynthesis was performed with the use of inverted triangle cannulated screws, a buttress plate fixed with one-third semi-tubular plate screws on the medial femoral neck, and the combination of these 2 methods. The groups were compared to the control group in terms of axial and torsional stiffness and maximum axial force. It was shown that the fixation method in which the combined method was used provided more stability in terms of both axial forces and torsional moments compared to the control group and other fixation methods.

In the literature, different fixation methods for the treatment of Pauwels type 3 femoral neck fractures have been examined in preclinical and clinical studies. Researchers have discussed whether half-thread screws or semi-and full-thread screws should be used together for neck shortening. Nevertheless, clinical investigations have not yet yielded conclusive findings.[4,6,12-15] While some studies indicate that the use of 4 screws is superior to 3 screws,[13,14] others suggest that the use of 3 screws is superior to that of 2 screws, but the use of 4 screws does not provide any additional benefit.[6,13] Discussion on the ideal screw configuration (parallel or divergent) or the type of screws to be used have yet to reach a consensus.

Holmes et al[15] found that the parallel arrangement was superior to the nonparallel arrangement in producing a controlled effect on the fracture line. Several studies in the literature have shown that the dynamic hip screw (DHS) method, which is preferred for femoral neck fractures, is superior to the use of cannulated screws.[16-18] However, in a biomechanical study on Pauwels type 3 fracture models, Kunapuli et al[7] reported that the inverted triangular configuration was superior to DHS. Kemker et al[4] also demonstrated that the inverted triangle configuration was superior to the DHS in Pauwels type 3 fractures. In a biomechanical study by Selvan et al[18] on synthetic bone models, the triangular configuration was found to have biomechanical superiority in Pauwels type 3 fractures. In a clinical study by Yang et al,[19] the inverted triangle configuration was superior to the classic triangle configuration in terms of the union rate. Li et al[12] obtained different results in all 4 groups in their finite element analysis, comparing different screw configurations in terms of stress distribution, strains in proximal fragments, and stress distribution around the screw holes. The authors concluded that the inverted triangle configuration was superior to the remaining methods in terms of these parameters. In light of the findings from these studies, we opted to use cannulated screw fixation rather than DHS in our study group. For the same reason, we included the inverted triangle configuration in our study group, not the classical triangle formation, for cannulated screw fixation. In the literature, it has been shown that the plate fixed to the medial side of the femoral neck creates a buttress effect, reducing the high complication rates by resisting the high shear forces that occur in Pauwels type 3 fractures. However, there is not yet a comprehensive series.[20,021]

Li et al[8] conducted a finite element analysis to compare the inverted triangle configuration, inverted triangle configuration, and screw fixation methods with a one-third semi-tubular plate on the medial femoral neck and the inverted triangle configuration with a medial anatomic buttress plate. They examined the femur's stress distributions, stress peaks, axis displacements, and 3 internal fixations. They found that the inverted triangle support with a medial and anatomical support plate was superior to the remaining groups in terms of stability. This was attributed to 2 factors: first, the plate was assumed to be suitable for the anatomy of the thigh, and second, the load applied to the plate was distributed across the plate.[8]

The results of the finite element analysis undertaken by Tianye et al[9] demonstrated that the fixation of the plate with cannulated screws in the central part of the femoral neck promoted healing of the fracture. The researchers recommended the utilization of a combined approach involving a medial buttress plate and cannulated screw fixation.[9]

Giardino et al[10] biomechanically compared the combination of 2 parallel cannulated screws and a horizontally inserted one-third screw for fixation of the created femoral neck fracture models to the use of a medial buttress plate in the first group. The application of cannulated screws with a medial buttress plate was determined to be superior to the isolated use of cannulated screws. In medial buttress plate fixation with cannulated screws, no separation was observed in the fracture, which was expected in Pauwels type 3 fractures. This was due to the medially applied plate converting shear forces into compressive forces and the parallel applied screws increasing screw compression at the fracture line.[10]

Ye et al[21] used cannulated screw wall and medial buttress plate fixation together in a clinical trial in which 28 patients younger than 60 years were followed up for 13.4 months. They reported union in 25 (89.3%) of the patients, nonunion in 3 patients (10.7%), implant failure in 10.7% (3 patients), lateral cutaneous nerve damage in one patient, and impingement in one patient.[21]

In our study, group 4 (inverted triangle configuration+medial buttress plate) was significantly superior to the remaining groups in terms of all 3 parameters (axial stiffness, torsional stiffness, and maximum axial force) ($P < .0001$). Group 2 (medial buttress plate) and group 3 (inverted triangle configuration) provided significantly weaker fixation than group 1 in terms of axial stiffness ($P < .05$). In terms of axial stiffness, group 2 provided weaker fixation than group 3 ($P < .05$). Group 3 was not superior to group 1 (control group) in terms of torsional stiffness ($P > .05$). Group 2 provided weaker fixation than group 1 in terms of torsional stiffness ($P < .01$). Group 3 was not significantly superior to group 1 in terms of maximal axial force ($P > .05$). Group 2 did not provide adequate fixation in terms of torsional stiffness compared to group 1 ($P < .01$). According to these results, the use of medial buttress plate fixation alone provided less stability than the other fixation methods. There is no study in the literature on the use of an isolated plate and screw osteosynthesis on the medial aspect of the femoral neck. We formed this group, considering its potential benefits for clinical practice. If the efficacy of this method is proven, it would allow for the operation to be performed with a single incision in a clinical setting, facilitating open reduction. In addition, the operation time would be shorter than the method involving the use of cannulated screws and medial buttress plate fixation. Although our results were not able to prove the efficacy of this method, with the introduction of different plate designs, isolated medial plate fixation may become an alternative to existing methods in the future.

The behavior of the implanted specimens is an equally important issue to consider in our biomechanically designed study. We used synthetic femoral models in our study. Since synthetic models are easier to store than human cadaver bones, there is no risk of biological contamination. In addition, this approach ensures a uniform physical standard among the specimens. Synthetic femoral models have typical characteristics in terms of their material composition as determined by the manufacturer, as well as their desirable geometric properties. Furthermore, their bone density is similar to that of normal human bones. Therefore, the relative bone density differences in cadaveric samples are not affected by relative bone density differences.[22] In addition, we used third-generation composite femur models in our study because it has been shown in the literature that their biomechanical behavior is similar to that of long human bones in terms of torsional behavior, response to bending forces, pullout strength, effective shear stress, and structural stiffness.[23]

A study conducted by Sağlam et al[24] examined similar parameters in groups that were designed in a similar manner to our study. One notable advantage of our study in comparison to cadaver studies is the use of a single type of bone model. Although there are studies examining the application of medial buttress plate fixation to the femoral neck in combination with other fixation methods, no study has investigated the efficacy of this technique alone.

This study has certain limitations inherent to its biomechanical design, including being performed in isolation from anatomical structures such as muscles, ligaments, and joint capsules; the inability to incorporate biological healing processes into the study; and the inability to fully account for forces exerted on the hip during daily activities. Another limitation is that the femoral bone models we used in our study were not osteoporotic; therefore, they did not reflect the implant behavior in patients with osteoporosis. However, the uniformity of the bone models provided standardization for the comparison of implant behaviors. An additional constraint arose in the process of creating the femoral neck fracture model, wherein the osteotomy was performed using a saw over the incision guide for the standardization of fracture configurations. In clinical practice, this method may cause limitations in the absence of dentition between the bone surfaces due to fracture, as would be the case in the real fracture line, as well as in imitating the friction between the interfaces.

When examining human biomechanics and the fracture healing process, it is known that this is a dynamic process that extends beyond the mere fixation of a fracture. The biomechanical comparison of fixation methods we discussed in our study helps illuminate only a part of this process. Due to the nature of our study, certain parameters were not included, such as the fatigue test, changes in the relationship between the implant and the bone over time, and the examination of the behavior of the implant during the fracture healing process. This can also be considered a shortcoming of our work.

Upon examination of the data obtained in our study, it was observed that there were notable differences between the specimens within the same group. Although we standardized all the specimens using a third-generation composite femur models, 3.5 mm screws, 6.5 mm half-threaded cannulated screws, and one-third semi-tubular plates obtained from the same manufacturer, it is plausible that other factors, which did not result in exclusion, could account for the observed differences in data between the specimens. For example, the observed variations could potentially arise from nonsignificant differences in strains that occurred during the process of preparing the specimens or fixing them with implants and PVC-polyester resin.

The use of manual methods in terminating our study may have also caused problems with standardization even among the researchers. We subjected the specimens to continuous testing until they reached a state of complete breakage. During this process, we examined the test data and made efforts to minimize potential errors in our manual termination criteria to acceptable levels. However, we cannot state that the criteria used for termination did not affect the test results, which can be considered another deficit of our study.

Although the current absence of clinical implementation of medial buttress plate fixation to the femoral neck without the use of cannulated screws, a method we employed in one of our study groups, can also be regarded as a limitation, it would be premature to assert that this method will not find its way into clinical practice in the future, particularly with the potential development of new plate screw designs.

This study revealed that in the fixation of Pauwels type 3 fractures formed on third-generation bone models, the utilization of half-thread cannulated screws in an inverted triangle configuration, along with a medial buttress plate, provided stronger fixation compared to other implant groups and the control group. According to the evaluation of the parameters, the isolated application of a medial buttress plate had poorer biomechanical properties than the remaining fixation methods and even the control group that did not undergo implantation.

Ethics Committee Approval: Ethics committee approval was not necessary due to the biomechanical nature of the study. The academic committee of the University of Health Sciences Department of Orthopedics and Traumatology provided clearance for the study (Approval No: 2019/08, Date: November 1, 2019).

Informed Consent: Informed consent was not necessary due to the biomechanical nature of the study.

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