EXPERIMENTAL STUDIES

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Influence of number and orientation of screws on stability in the internal fixation of unstable femoral neck fractures

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Objective: The aim of this study was to biomechanically compare 3 different cannulated screw configurations used in internal fixation of unstable femoral neck fractures.

Methods: The study included 28 synthetic left femurs randomly divided into 4 equal groups. Samples in the first 3 groups were osteotomized in the basicervical region to create Pauwels Type 3 fractures. Fixation was carried out using cannulated screws. In Group 1, four screws were used including 3 in an inverted triangle configuration in parallel with the neck and the fourth screw transversely into the calcar. In Group 2, three screws were used including 2 in parallel with the neck and the third transversely into the calcar. In Group 3, three screws were used in an inverted triangle configuration in parallel with the neck. No osteotomy or fixation was carried out in Group 4. Load test was performed on all the groups and the strength of the screw fixations against axial load and their amount of relocation were measured.

Results: Average maximum strength was 36.1±3.2 N/mm^2 in Group 1, 27.3±4.1 N/mm^2 in Group 2 and 21.9±3.2 N/mm^2 in Group 3. The average relocation in the line of osteotomy in the moment of average maximum stress (21.9±3.2 N/mm^2) was 11.5±2.1 mm in Group 3, 6±1.3 mm in Group 2 and 5.8±1.1 mm in Group 1 ($p<0.05$). It was also observed that while the relocation in the moment of average maximum stress (27.3±4.1 N/mm^2) was 9.1±1.7 mm in Group 2, the deformation under the same stress value was 9±1.7 mm in Group 1 ($p>0.05$).

Conclusion: The use of a transverse screw in the calcar in addition to cannulated screws parallel to the neck appear to provide stability benefit in the treatment of unstable femoral neck fractures.

Key words: Cannulated screw; femoral neck fractures; fixation; unstable.

Femoral neck fractures are rarely seen in the young population and their incidence increases with age.[1] The most preferred options in the treatment of such fractures are internal fixation and primary arthroplasty. Patient age is the main determinant in the selection of treatment. Arthroplasty is often preferred for older patients and internal fixation in younger ones.[2-4] Fixation by multiple screws driven in parallel with the neck axis is one of the

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most commonly used methods of internal fixation. The position and number of screws, however, may depend on the surgeon's preference[5] and, along with a patient's bone density, influences the screw's fixation strength and the success of treatment.[6,7]

Nowadays, fixation using 3 cannulated screws in an inverted triangle configuration in parallel with the neck is recommended in the treatment of femoral neck fractures.[4,8,9] This fixation method contributes to the recovery of a fracture through compression on the fractured pieces.[8]

Femoral neck fractures have been classified in three categories by Pauwels based on the orientation of the line of fracture.[10] Type 3 fractures are often observed in young adults in cases of high-energy trauma. As such fractures are mechanically less stable in the vertical position, postoperative problems regarding fixation are frequently experienced.[11] Loss of reduction (varus deformity) following an internal fixation may result in union problems and femoral head necrosis by causing blood stream deterioration. Adverse results ranging between 20 to 48 percent following fixation of femoral neck fractures using 3 parallel cannulated screws have been reported in the literature.[12]

The aim of this study was to biomechanically compare 3 different cannulated screw configurations in the treatment of unstable femoral neck fractures.

Materials and methods

Study protocol was determined using similar previous studies as a guide.[5,6,13-15] Our study included 28 reinforced (with a resistance against up to 1530 N in mechanical tests) third generation composite synthetic left femoral models (Model: FMR-01 New Third Generation Composite Left Femur; Selbones Research Lab., Kayseri, Turkey) randomly divided into 4 groups of 7 femurs.

Fixation was carried out by a single surgeon (S.A.G.) using a 6.5-mm half-grooved (32 mm) cannulated screw (TST Ortopedi, Pendik, Turkey). Separate screws were used for each femoral model. After the guide wires were placed in the required angles and numbers under fluoroscopy in accordance with the study protocol, drilling was performed over the wires. Guide wires were removed and a power-saw with a low oscillation was used to cut the femoral neck from the basicervical region so as to create a Pauwels Type 3 fracture (a 70-degree angle to an imaginary line which is perpendicular to the longitudinal axis of the femur).[13]

After the line of osteotomy was reduced and the guide wires were placed, fixation with cannulated screws was carried out using a torque screwdriver. In Group 1, four screws were used (3 in an inverted triangle configuration in parallel with the neck and 1 transverse into the calcar) (Fig. 1a), 3 screws in Group 2 (2 placed one on the top of the other in parallel with the neck and 1 transverse into the calcar) (Fig. 1b), and 3 screws in Group 3 (3 in an inverted triangle configuration in parallel with the neck) (Fig. 1c). Group 4 was considered the control group; no osteotomy or fixation was performed. The parallel screws were fixed first, followed by those transverse

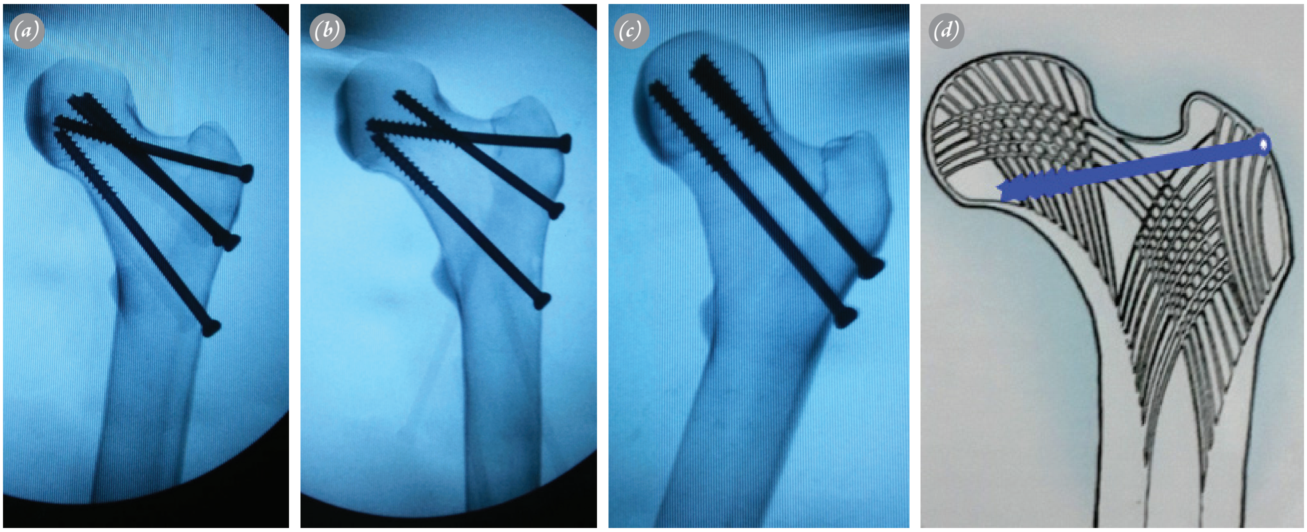

Fig. 1. **(a)** The first group; fixation by 4 screws (3 in an inverted triangle configuration in parallel with the neck, and the fourth screw transverse to the calcar). **(b)** The second group; fixation by 3 screws (2 one on the top of the other in parallel with the neck and the third transverse to the calcar). **(c)** The third group; fixation by 3 screws (all 3 in an inverted triangle configuration in parallel with the neck). **(d)** Schematization of the screw driven transversely into the calcar. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

to the calcar. Tightening compressions were carried out in the same order. The screws placed transversely into the calcar were driven in a higher angle to the primary compressive trabeculae from the greater trochanter's superior to the posteromedial of the neck (Fig. 1d). Screw placement was checked using fluoroscopy.

Synthetic femoral models were cut perpendicularly from the middle diaphyseal region and positioned in the device in accordance with the terminal stance phase of walking (at a 25° of adduction in the coronal plane and at neutral position in the sagittal plane)[16] (Fig. 2). Biomechanical tests were carried out in the Technology Engineering Material-Mechanical Laboratory at Fırat University using the Shimadzu Autograph AG-X / 50 kN (Shimadzu Corp., Kyoto, Japan) device. All the samples were placed between two metal clamps and subjected to a stress sufficient to create 10 mm compressive deformation by a load of 5 N/mm^2 preload in two minutes.[5,14,15] Measurements were recorded using Trapezium 2.0 v.2.23 (Shimadzu Corp., Kyoto, Japan) software. The ultimate compressive strength and the ultimate deformation were determined. Relocation curves relating to pressure (N/mm^2) were recorded by a computer-based data collection system.

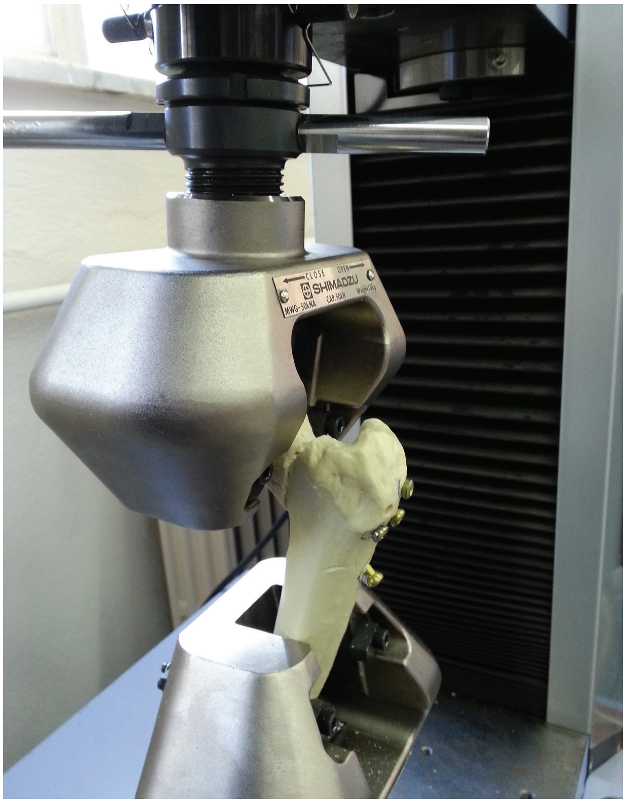

Fig. 2. Positioning of the synthetic femur samples within the device. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

Statistical analyses were performed using SPSS 15.0 (SPSS Inc., Chicago, IL, USA) software. Data distribution compliance was evaluated using the one-sample Kolmogorov-Smirnov test. Results were reported as average±SD. Groups were evaluated using the one-way variance analysis and Tukey's test was used for group differences. Level of significance was accepted as $p<0.05$.

Results

Groups had normally distributed maximum strength values ($p>0.05$). The average maximum strength (stress=force/area) was 102±1.4 N/mm^2 in the control group (Group 4). The average maximum strength in Group 1 was 36.1±3.2 N/mm^2, 27.3±4.1 N/mm^2 in Group 2 and 21.9±3.2 N/mm^2 in Group 3. A statistically significant difference was determined among the three groups in terms of their maximum strengths ($p<0.001$ for all groups) (Fig. 3).

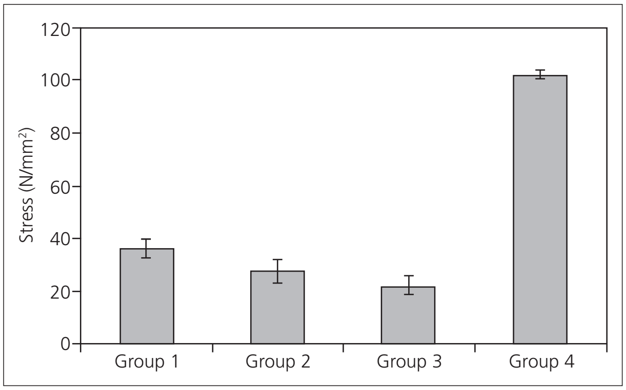

Fig. 3. Average maximum strength and standard deviation graph.

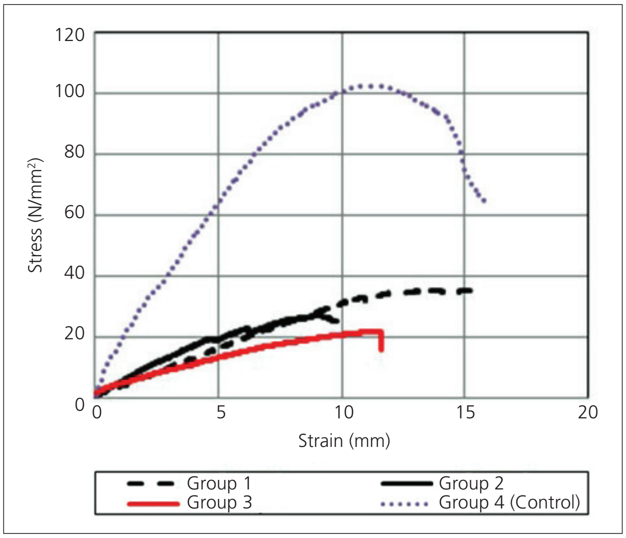

Fig. 4. The curve of strength/dislocation. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

Group 3 had the lowest stability among the osteotomized groups and its average maximum strength was accepted as the comparison value of the amount of relocation in the area of osteotomy. Thus, in the synthetic bone models which were subjected to test so as to create a compression stress of 10 mm per minute by a preload of 5 N/mm^2, the average relocation in the line osteotomy in the moment of average maximum strength (21.9±3.2 N/mm^2) was 11.5±2.1 mm in Group 3, 6±1.3 mm in Group 2, and 5.8±1.1 mm in Group 1 ($p<0.05$). It was also observed that while the relocation in the moment of average maximum strength (27.3±4.1 N/mm^2) was 9.1±1.7 mm in Group 2, the deformation under the same stress value was 9±1.8 mm in Group 1 ($p>0.05$) (Fig. 4).

Discussion

Although many biomechanical studies have been carried out to determine the most appropriate method for a stable fixation in the surgical treatment of unstable femoral neck fractures, debate continues regarding the ideal fixation method.[5,6,14,15,17,18] The current study carried out a biomechanical comparison of 3 different cannulated screw configurations in the treatment of Pauwels Type 3 femoral neck fractures. The highest average maximum strength among the treatment groups was obtained in Group 1 (3 screws in an inverted triangle configuration in parallel with the neck and 1 transverse to the calcar). Among the groups in which 3 screws were used, Group 2 (2 parallel screws vertical to the neck and 1 transverse to the calcar) had a higher maximum strength than Group 1 (inverted triangle in parallel with the neck).

Pauwels classified femoral neck fractures based on the orientation of the horizontal gradient of the line of fracture.[10] In Pauwels Type 3 fractures, a less compressive load and a higher dislocation stress and varus load are dominant.[10,19] The more vertical and lateral the line of fracture is, the more unstable it is.[13] High rates of complications are associated with the internal fixation of such unstable fractures.[4,10,13] In our study, synthetic femoral neck osteotomy from the basicervical region was standardized as Type 3 according to the Pauwels classification.

In the internal fixation of Pauwels Type 3 femoral neck fractures, dynamic hip screw (DHS) and cannulated screw are frequently preferred. While a more stable fixation is obtained in osteoporotic fractures by DHS, this technique necessitates a larger soft tissue dissection.[2,20] The literature includes diverse studies including those which report that DHS provides a more stable fixation as compared with cannulated screws,[16,17,21,22] those which report that there is not difference[2,14,23] and even some which suggest that better results are obtained with cannulated screws.[24]

One of the methods used for the internal fixation in femoral neck fractures is the utilization of multiple cannulated screws.[4,7-9,12] It has been reported that the number and orientation of screws are very influential in fixation stability,[6] although different results have been found in many other studies.[5,6,15,18,25] Walker et al. fixed cadaver femoral neck fractures using 2 or 3 cannulated screws driven by the angles of 135°, 145° and 150° and reported no difference between groups in axial load tests but that they obtained a more stable fixation at a high angle (150°) in bending tests, and that fixation by 2 screws was sufficient.[25] Zdero et al.[5] found that driving screws in the inverted triangle configuration close to the cortical walls is more stable than the inverted triangle configuration in which screws are driven closely to each other. Tan et al., on the other hand, reported that a more stable fixation was provided by 2 screws installed horizontally in a parallel position compared with 2 screws installed vertically in a parallel position.[6] Alves et al.[15] compared a hydroxyapatite-reinforced fixation with 3 partially-grooved screws in a parallel triangular configuration on one side and fixation using 3 fully-grooved screws in a parallel triangular configuration and alternatively by 3 non-parallel and partially-grooved screws without hydroxyapatite-reinforcement, on the other. The authors reported that the hydroxyapatite-reinforced parallel screws were more stable but that non-parallel screws produced weaker results than the fully-grooved parallel screws in those fixations carried out without a hydroxyapatite-reinforcement. In our study, the group with divergent screws (2 parallel to the neck and 1 transverse to the calcar) (Group 2) produced more stable results than Group 3 with parallel screws (standard inverted triangle configuration).

Debates continue regarding screw orientation in the fixation of such fractures using cannulated screws. In clinical studies, Huang et al.[26] reported that parallel screw driving is superior while Probe and Ward,[27] Filipov,[12] and Papanastassiou et al.[28] stated that divergent screw configurations produced better results. Although it has been suggested in previous studies[29] that placement of parallel cannulated screws in an inverted triangle configuration enabled stable fixation of fractures in biomechanical terms, adverse results of between 20 and 48% following this method have been reported.[12] These high rates of failure may be explained by biomechanical flaws.[30]

Parker and Blundell argued in a meta-analysis that it was impossible to determine the sufficient number and type of screws.[31] Spangler et al. reported that they were unable to find a correlation between the angle of screws and the emergence of complications.[32]

The literature also does not provide a consensus regarding the contribution of a fourth screw to the stability in the internal fixation of femoral neck fractures. While some studies have suggested that the addition of a fourth screw would not provide a mechanical benefit,[30,33] others have shown that utilization of a fourth screw increased stability.[7] Kauffman et al.[18] reported that fixation using 4 screws enabled better stabilization than 3 screws in posterior fragmented femoral neck fractures. In the current study, stabilization was better in the group in which 4 screws were used (Group 1) than the groups in which 3 screws were used (Groups 1 and 2) ($p<0.05$).

Limitations of the study included the use of a composite synthetic femur model and the fact that only axial compressive loads were applied in the biomechanical tests. Utilization of human cadaver femurs in laboratory tests is still considered to be the golden standard by many researchers. Limitations in terms of donors and ethical regulations, however, have resulted in the frequent use of femur composite analogs.[34] In addition, the composite femurs which are modeled for healthy young bones rather than for osteoporotic femur neck fractures are designed to substantially reduce the variability in the experiments and to mimic the physical characteristics of the bone.[15] We are of the opinion, therefore, that the use of cadaver bone would not allow an objective evaluation of the influence of screw configurations on the stability due to the difference of bone diameter and personal variances of bone density.

In conclusion, the addition of a screw driven transversely into the calcar in addition to cannulated screws placed in parallel with the neck will provide a beneficial contribution to fixation stability in the treatment of unstable femoral neck fractures. However, further clinical studies are needed to support our biomechanical findings.

Conflicts of Interest: No conflicts declared.

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