Experimental Investigations On Three Fixation Methods (CSs, DHS+DS, And PFLP) Of Femoral Neck Fractures In Young Adults

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Introduction: Femoral neck, vertically oriented fractures in young patients are usually caused by high-energy trauma. Although efforts are focused on preserving the femoral head in young patients, because of domination of shear forces, vertical femoral neck fracture is a problematic orthopedic injury [1,2]. Due to controversy regarding which method of fixation is the best, the purpose of this study was to find the most stable fixation method for this kind of fracture. This study consisted of comparing biomechanical stability of cadaveric bone samples for 3 different fracture fixation techniques, i.e. cannulated screws (CSs), dynamic hip screw with derotational screw (DHS+DS), and proximal femoral locking plate (PFLP). In most previous studies, femoral neck instability was evaluated based on the alterations in the fracture gap after osteotomy and reduction. The techniques used in this study applied motion capture analysis to evaluate relative motions between the fractured fragments [3]. Thus, stability of fixed fracture that is a prerequisite of primary bone healing was investigated.

Methods: Twelve fresh frozen cadaveric femurs including two women and ten men (age at time of death, 23-56 years) with no known previous history of hip pathology were harvested at autopsy. The specimens were assigned to 3 groups that were matched for mean bone mineral density and stiffness of intact bone. Vertical fractures were artificially mimicked in the specimens by an orthopaedic surgeon, and the broken specimens were fixed using 3 different kinds of implants (Fig. 1a). The samples then were positioned in 25 deg. of adduction and loaded using a quasi-acetabulum fixture in an incremental; cyclic; and failure phases (Fig.1b). In order to measure interfragmentary movement, five pairs of markers (three on the anterior surface and two on the posterior side) were placed around the osteotomy, 10 mm apart from each other, as well as with one marker on the femoral shaft, and the corresponding marker on the adjacent femoral head (Fig.1c) [3]. During loading, relative movement of each pair of markers was traced by a digital Casio EX-FH100 camcorder. The loading steps to simulate partial weight-bearing in the immediate postoperative period were as follows: (I) Incremental loading: each specimen was loaded to a maximum of 700 N at a rate of 1 mm/min displacement before and after fixation; (II) Cyclic loading: each sample was tested under cyclical loading in which a 100-700 N force was applied at a frequency of 3 Hz for 10,000 cycles; and (III) Failure loading: specimens were loaded at a rate of 1 mm/min to reach failure criterion, defined as downward femoral head displacement or fracture displacement greater than 5 mm, or instability observation in the load-displacement curve [4]. Due to the small number of samples (4 samples in each group), nonparametric Kruskal-Wallis and Mann-
Whitney U tests were performed, and the level of significance was determined to be \( p < 0.05 \). The software package SPSS (V.19) was also used for the statistical evaluations.

**Results:** The average biomechanical properties of the tested fixation techniques can be found in Table 1. The differences in all biomechanical parameters were statistically significant among tested groups (\( p < 0.05 \)). Relative stiffness (stiffness of bone-implant structure after fixation per stiffness of intact bone), downward femoral head displacement, failure load, and failure energy for the DHS+DS method of fixation are significantly different from CSs technique (\( p < 0.05 \)). Hence, the strongest construct was the DHS+DS and the weakest structure was CSs. There were no significant differences in failure load and failure energy between the PFLP and CSs techniques (\( p > 0.05 \)). Also, there were no significant differences in relative stiffness and femoral head displacement between the PFLP and DHS+DS groups (\( p > 0.05 \)). Thus, PFLP structure was stronger than CSs construct. Figure 2 shows typical curves of the maximum change in relative position of the fractured fragments and their components (axial and shear relative position, respectively parallel and perpendicular to the fracture line) at each loading phase for the tested fixation methods. Comparing trends of interfragmentary movement-load curves among different groups demonstrated that the DHS+DS method of fixation can keep the proximal and distal segments connected together, but PFLP and CSs techniques could not do it. Also, PFLP group represented fewer changes in relative position of the fractured fragments compared to CSs group. In addition trends of axial interfragmentary movement-load curves showed axial compression in DHS+DS technique for all locations around the fracture site. Despite of this, PFLP and CSs groups represented the femoral head toggling and rotation which were fewer for PFLP method of fixation. Finally, trends of shear interfragmentary movement-load curves demonstrated maximum shear and rotation resistance for the DHS+DS group followed in a descending order by PFLP and CSs techniques. All samples survived during both incremental and cyclical loading. Failure mode of the DHS+DS group was sliding and a slight toggling; while it was sliding, toggling, and rotation for PFLP and CSs.

**Discussion:** Dominance of shear forces in vertical femoral neck fractures causes femoral head toggling. Thus, stable fixation method should provide enough resistant against toggling during the course of bone healing process [2]. According to the biomechanical parameters and interfragmentary-load curves, the specimens fixed with DHS+DS provided the greatest resistance against femoral head toggling and rotation compared to two other fixation methods, i.e. PFLP and CSs (see Table 1 and Fig 2). Although there were no significant differences in failure load and failure energy between the PFLP and CSs methods of fixation, stiffness, downward femoral head displacement, and interfragmentary movements of the PFLP construct showed that toggling and rotation resistance of the PFLP is greater than that of the CSs method of fixation. This study has several limitations including: fractures were created by a smooth saw; and physiological force components acting across the hip were neglected.

**Significance:** Since there is not unique universally accepted method of fixation for the vertical fracture of femoral neck in young patients, the main goal of this research was to make comparisons among three commonly used fixation techniques using an *in-vitro* quasi-experimental cadaveric approach. The results of this research suggest that, based on the clinical advice that restricted weight-bearing regimen should be applied in the postoperative rehabilitation protocol, the priority order of selection for fixation technique of vertical femoral neck fracture in young patients is: DHS+DS method, then PFLP technique, and finally CSs method.
Figure 1. a) Fractured femurs fixed by three fixation techniques. b) Test setup, black arrow shows downward femoral head displacement. c) Femoral neck viewed from: (A) anterior side, and (B) posterior side, showing the osteotomy with visible markers. Locations of markers are identified: 1) ant-inf, 2) ant-mid, 3) ant-sup, 4) pos-inf, and 5) post-sup.

Table 1. The average biomechanical properties of three different fixation methods (CSs, DHS+DS, and PFLP)

<table>
<thead>
<tr>
<th>Fixation method</th>
<th>Relative Stiffness</th>
<th>Downward femoral head displacement (mm)</th>
<th>Failure load (kN)</th>
<th>Failure energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSs</td>
<td>0.27 ±0.07</td>
<td>4.71 ±0.96</td>
<td>2.01 ±0.46</td>
<td>3.17 ±0.69</td>
</tr>
<tr>
<td>DHS+DS</td>
<td>0.58 ±0.06</td>
<td>2.06 ±1.06</td>
<td>4.61 ±0.73</td>
<td>11.04 ±2.95</td>
</tr>
<tr>
<td>PFLP</td>
<td>0.51 ±0.11</td>
<td>2.43 ±0.56</td>
<td>2.54 ±0.86</td>
<td>5.06 ±2.35</td>
</tr>
</tbody>
</table>
Figure 2. Typical curves of interfragmentary movement for: A) DHS+Ds group; B) PFLP group; and C) CSs group. Each figure consists three pictures that show respectively relative, axial, and shear position of the fracture fragments versus different loading steps for various locations around the fracture site (step1: initial position, step2: incremental loading (at max load), step3-6: cyclic loading).