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Changes In Mechanical Strength of Compression HIP Screws in Relation to Design Variations - A Biomechanical Analysis

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Abstract: Compression Hip Screw (CHS) is one of the most widely-used prostheses for the treatment of intertrochanteric fractures because of its strong fixation capability. Fractures at the neck and screw holes are frequently noted as some of its clinical drawbacks, which warrant more in-depth biomechanical analysis on its design variables. The purpose of this study was to evaluate changes in the strength with respect to the changes in design such as the plate thickness and the number of screw holes. Both mechanical test and FEM analysis were used to systematically investigate the sensitivities of the above-mentioned design variables. For the first part of the mechanical test, CHS (n=20) were tested until failure. The CHS specimens were classified into four groups: Group I was the control group with the neck thickness of 6-mm and 5 screw holes on the side plate, Group II 6-mm thick and 8 holes, Group III 7.5-mm thick and 5 holes, and Group IV 7.5-mm thick and 8 holes. Then, the fatigue test was done for each group by imparting 50% and 75% of the failure loads for one million cycles. For the FEM analysis, FE models were made for each group. Appropriate loading and boundary conditions were applied based on the failure test results. Stresses were assessed. Mechanical test results indicated that the failure strength increased dramatically by 80% with thicker plate. However, the strength remained unchanged or decreased slightly despite the increase in number of holes. These results indicated the higher sensitivity of plate thickness to the implant strength. No fatigue failures were observed which suggested the implant could withstand at least one million cycles of fatigue load regardless of the design changes. Our FEM results also supported the above results by showing a similar trend in stress as those of mechanical test. In summary, our biomechanical results were able to show that plate thickness could be a more important variable in design for reinforcing the strength of CHS than the number of screw holes.

Key words : Compression Hip Screw (CHS), Design variables, Intertrochanteric fracture, Mechanical test, Finite element analysis (FEA)

INTRODUCTION

Incidence of intertrochanteric fractures has gone up steadily over recent years with rise in the elderly population [1~6]. The femoral head and neck regions become very susceptible to various types of fractures as bone density of the people decreases with age. Its surgical management requires early and strong fixation capabilities at the fractured planes to promote rapid bony fusion. Internal fixation devices such as the ender nails, gamma nails, and compression hip screws (CHS) have been developed. Particularly, the CHS is one of the most popular and effective prostheses because it provides strong compression forces across the fracture planes with its lag screws and the side plate [2, 3]. However, various types of fractures at the neck region and the cracks propagating from the screw holes on the side plate are often cited as some of its inherent problems. Manufacturers and researches have been trying to address these issues by improving the mechanical strength of the implant materials and by reducing areas of stress concentration through design changes.

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In this study, we investigated the effects of the changes in design variables on the strength of the CHS. Particularly, changes in the plate thickness and number of screw holes at the side plate were studied in relation to the strength of the implant. Failure test, fatigue test and finite element analysis were done for the research.

MATERIALS AND METHODS

Biomechanical Test

Specimen Preparation

20 CHS (Solco Biomedical Co. Ltd., South Korea) with an inclination angle of 135° between the barrel

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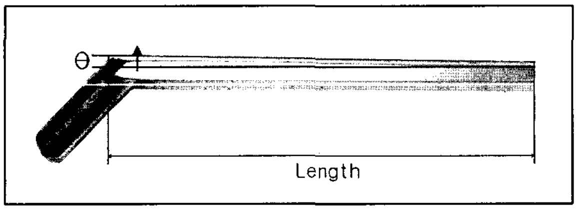
and the long axis of the side plate were used in this study. All side plates and the barrel were made of Grade 2 titanium and the lag screws (length : 80mm) of Ti6Al4V.

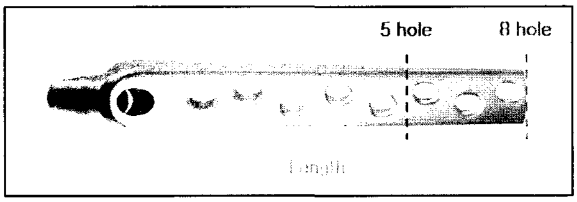
Specimens were classified into four groups (n=5 each): the control was the standard CHS with the plate thickness of 6-mm and 5 screw holes (Group I), Group II with three more screw holes on the side plate added to Group I, Group III with thicker side plate by 1.5-mm on the superior region, and Group IV with both thicker side plate and three more holes. It should be noted that thickening of the plate from 6-mm to 7.5-mm was done at the superior region of the side plate by introducing tapering angle (θ)of 1°(Fig. 1). Resulting design specifications for each group are listed in Table 1.

Table 1. Design specification of CHSs

CHS Group	I	II	III	IV
Plate thickness(mm)	6	6	7.5	7.5
No. of screw holes	5	8	5	8



(a)



(b)

Fig. 1. Design variables : (a) tapering angle θ, (b) plate length

All testing procedures were done according to the guidelines suggested on ASTM F384-00[7]. A jig which is capable of transmitting a vertical load to the lag screw head in a continuous fashion was designed and fabricated to follow the testing guideline of ASTM(Fig. 2).

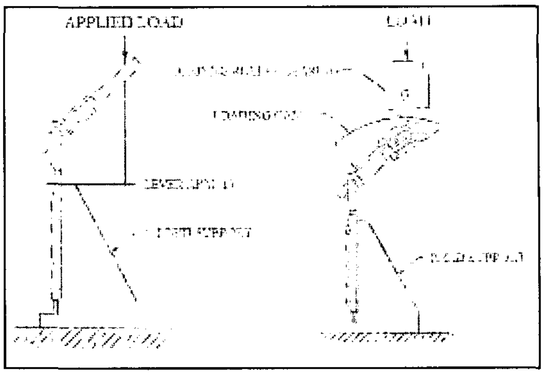


Fig. 2. Testing configurations for CHS as suggested in ASTM

In this study, a jig was custom-designed to simulate physiologically relevant loading and boundary conditions as closely as possible while following the guidelines suggested in ASTM [10] (Fig. 3). Its upper part incorporated a ball-cam and rail bearing for the exact load transmission in compression. In addition, its base was designed to hold the side plate of the CHS specimen with surgical screws to replicate the clinical conditions as closely as possible.

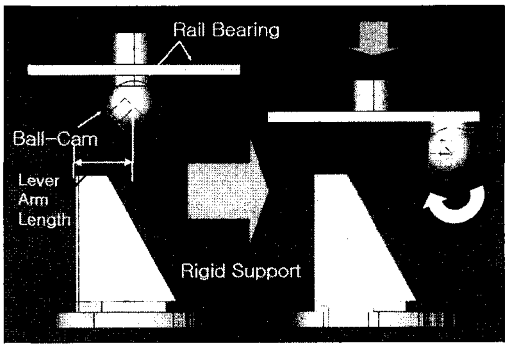


Fig. 3. Schematic diagram of the custom-designed jig

Failure Test

Each of the specimen(n=3 for each group) and the jig were mounted on the mechanical testing machine (MTS 858, MTS system Corp., MN, USA) for the failure test (Fig. 4).

compression load was applied at a rate of 0.17mm/sec with the maximum displacement set at 60mm. The failure loads were determined by 0.2% offset method which is 0.2% of the lever arm length. Corresponding bending strengths were also calculated from the failure loads (F_{max}) and the lever arm lengths (L) based on Equation (1).

Bending Stiffness (N·mm) = $F_{max} \times L$ ---------- (1)

All of the results were analyzed by ANOVA test with SPSS 11.0®(SPSS Inc., IL, USA) for comparison of correlations.

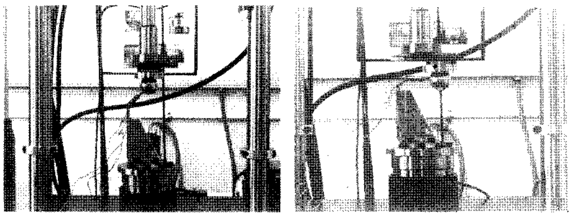

(a) (b)

Fig. 4. Experimental test of the CHSs with a jig : (a) before the compression load and (b) after the compression load

Fatigue Test

Subsequently, fatigue tests were done (n=2 for each group) to determine the fatigue life. Fatigue loads were applied at 5Hz with data acquisition rate of 20/sec. The 50% and 75% of the corresponding failure loads that was obtained earlier from the failure tests were used for each group. Maximum number of loading cycle was set at 1 million cycles according to ASTM. It was intended to record the number of cycles to fatigue failure if the specimen fails before reaching 1 million cycles.

Finite Element Analysis

Finite element models of various CHSs were constructed to analyze the change in stress distribution due to changes in thickness and hole numbers. A particular attention was given at the neck and the screw hole regions that have been cited as fracture-prone (Fig. 6). Lines of FE models were made based on their actual CAD drawings. 8-nodes brick elements were used and appropriate isotropic material properties were assigned (Table 2). ANSYS 6.0^{R} (Swanson Analysis Systems, Inc., Houston, PA, U.S.A.) was used for finite element analysis.

To reflect the same loading and boundary conditions as in the biomechanical test, a compression load of 300N was applied at the lag screw head and all screw holes and contact areas between side plate and the jig were restricted in all directions[8, 9] (Fig. 5).

Table 2. Material properties of CHS

Components	Lag screw (Ti6Al4V)	Side plate (Ti Grade2)
Young's Modulus(GPa)	113.8	102
Possion's ratio	0.342	0.34

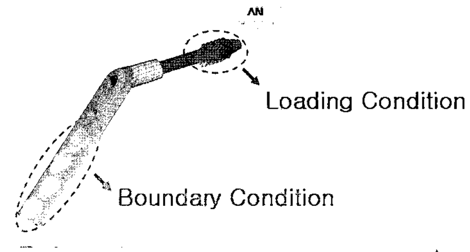


Fig. 5. Loading & Boundary conditions of Finite element models

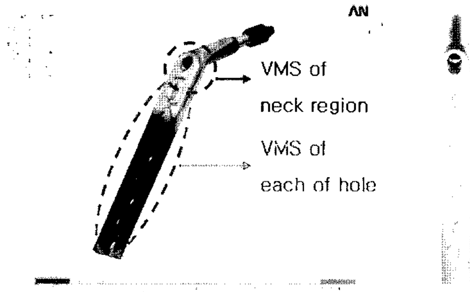


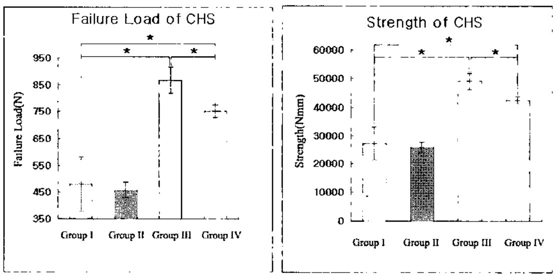
Fig. 6. Analysis of peak von-Mises stresses at CHSs and allotment of a number at each screw hole

Finite element models were validated by comparing its results to the displacement data of the failure tests.

RESULTS

Experimental Results

Group III was found to be the strongest type with the failure load of 867N and the bending strength of 49KN-mm, followed by Group IV (Fig. 7).



(a) (b)

Fig. 7. Failure loads and strength results from the failure tests of the CHSs : (a) Failure loads, (b) Strengths(* : $p<0.05$)

Adding 1.5mm of the plate thickness (25% increases in the thickness) reinforce the CHS by 80% (480N in Group I vs. 867N in Group III) and it was statistically significant ($p<0.05$). However, increase in the number of screw holes did not enhance the strength of the CHS. Rather, slight decrease (about 15%) in strength was noted and it was statistically significant between Groups III and IV ($p<0.05$).

No deformations and failures due to fatigue were found in all specimen groups after 1 million cycles regardless the magnitude of fatigue loads (50% and 75% of the failure loads).

Finite Element Analysis Results

Peak von-Mises stresses at the neck region are tabulated in Table 3.

Table 3. Peak von-Mises stress at the neck

CHS Group	I	II	III	IV
VMS(MPa)	175	152	119	111

Group I (175MPa) showed the highest stress but Group IV (111MPa) had the lowest. Stresses were appeared to be more concentrated around the perimeters of the lag screw holes than at the junction between the barrel and the side plate.

The highest peak von-Mises stresses were found at the most superior location (referred as the hole number 1 in Fig. 8)

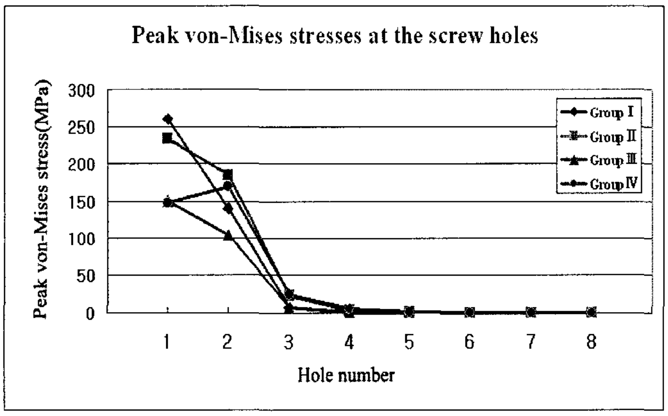


Fig. 8. Peak von-Mises stresses of the screw holes

Stresses were concentrated largely at the superior region and dropped considerably after hole number 3 in causal direction.

DISCUSSION

In this study, both biomechanical tests and finite element analyses showed that the thickness was a far more effective and sensitive design variable for the reinforcement of the CHSs than the screw hole numbers. It was also indicated that more screw holes on the side plate rather decreased the overall strength of CHSs.

It should be noted that all the experimental conditions provided by ASTM were based on the ideal surgical conditions in which the CHSs were assumed be securely fixed . The rigid support was made of SUS316L that is far greater in strength than titanium alloys to delineate effects of the design factors of CHSs. Actual clinical results may be different depending on bone densities and conditions of the host bone, surgical circumstances, and post-op activities of the patients. Further in-vitro tests with cadaver or animal specimens will be able to add more insights.

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