Analysis on Biomechanical Characteristics of Shape Memory Alloy Fixation Grip for Femoral Fractures

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Abstract. As life expectancy has increased with the advancement of medical technology, the frequency of femur fractures has also increased. The conventional treatment utilizes a bone fixation plate and screw system. However, because the screws are inserted into the bones, it can cause bones to get crushed and leave holes during removal of the screws. For the reasons above, secondary fractures can occur. In this study, the feasibility of a fixation grip which is composed of a shape memory alloy was investigated to resolve the disadvantages of bone fixation plates and screws by compressive and torsional analysis.

Keywords: Shape memory alloy, Fixation grip, Femur fracture, Finite Element Analysis, Biomechanical Characteristics

1 Introduction

South Korean society is aging rapidly. It has been reported that elderly population is expected to be approximately 5.4 million in 2010 [1]. The population is expected to become an aged society by 2026. As the elderly population rate is increasing, so are the femur fracture rates. [2].

Femur fractures include simple and complex fractures. Commonly, an expert surgeon considers the fracture’s characteristics for operation. In some cases, fixation nails are inserted into the bone marrow cavity. In other cases, bone fixation plates and screws are tightened upon the surface of the fractured region. However, fixing screws on the bones directly, may cause bone deformation or may crush the bones. Therefore, after treatment, the screws are left in the bones. Thus, the remaining holes may cause secondary fractures [3]. For the reasons above, the bone fixation plate and screw system is difficult use to patients who suffer from osteoporosis or are advanced in age. However, for patients who cannot undergo operations, bone restoration requires a longer time and potential complications may lead to the patients’ death [4].

The first alternative to overcome the limitations of the bone fixation plate and screw system, is to use smaller components to reduce the size of holes upon the bones [5]. This method improves treatment quality, but holes are left after removing the
screws. Thus it is not appropriate for elderly patients. To overcome these problems, a shape memory alloy has been employed to fix the fractured region instead of fixation plate and screws and clinical reports have been documented [6][7][8].

In this study, we have investigated the feasibility of a shape-memory-alloy grip for bone fixation by using biomechanical analysis. To analyze the shape-memory-alloy, the finite element analysis was employed for compressive and torsional analysis of the bone fixation grip which consists of shape-memory-alloy. The alloy was analyzed by finite element analysis for compressive and torsional analysis.

2 Method

2.1 Design of Shape-memory-alloy Fixation Grip for Femoral Fracture

Brojan’s study [9] and Hassan’s study [10] suggested the concept of fixation grips made of shape memory alloy (Fig 1). The fixation grip surrounds the fracture instead of directly on the fractured area. In this study, the concept of the two studies was referred to, while performing bone fixation grip modeling (Fig 2).

![Fig. 1 Concept of Shape-memory-alloy fixation grip [9][10]](image)

2.2 Design of Femoral Fracture Model

To collect basic information concerning designs of femur fracture fixation plate...
models, 3-dimensional femur models were reconstructed using commercial software (Mimics 16.0, Materialise) based on CT (Computed Tomography) images (Pixel Size: 0.832 mm, Slice Increment: 1.0 mm / provided by KISTI (Korea Institute of Science and Technology Information)) of 10 Korean cadavers (Fig 3). The cross section of the femoral shafts were measured. The average length was found to be 31mm and cortical bone thickness was found to be 7mm [11]. Femur fracture models were formed in a cylinder shape following the figures (Fig 4).

![Fig. 3. Femur model and Measurement of femur cross section](image)

![Fig. 4. Simplified femur fracture model](image)

### 2.3 Material Properties

As for materials used in the analysis, elderly femur property values were applied based on the previous study (Table 1). Property values of shape memory alloy components were set in reference to shape memory alloy experiment and analysis data (Table 2).

#### Table 1. Mechanical properties of elderly femur [12]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus</td>
<td>16,700MPa</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.26</td>
</tr>
</tbody>
</table>

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Table 2. Mechanical properties of shape memory alloy [13]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young's Modulus</td>
<td>75,000 MPa</td>
</tr>
<tr>
<td>Passion's ratio</td>
<td>0.33</td>
</tr>
<tr>
<td>Hardening parameter</td>
<td>500 MPa</td>
</tr>
<tr>
<td>Reference Temperature</td>
<td>5 ℃</td>
</tr>
<tr>
<td>Elastic Limit</td>
<td>300 MPa</td>
</tr>
<tr>
<td>Temperature Scaling Parameter</td>
<td>7.5</td>
</tr>
<tr>
<td>Maximum Transformation Strain</td>
<td>0.08</td>
</tr>
<tr>
<td>Martensite Modulus</td>
<td>28,000 MPa</td>
</tr>
<tr>
<td>Lode Dependency Parameter</td>
<td>0</td>
</tr>
</tbody>
</table>

2.4 Construction of Finite Element Model

To implement the finite element analysis for compression and torsion, the bone fixation grip model under 2.1 and femur model under 2.2 were constructed as the finite element model (Fig 5). The solid elements of ANSYS (Solid186, Solid187) were applied to the finite element models of the cylinder and the bone fixation grip, and the shape memory effect function of ANSYS 14.5 was utilized (Table 3).

![Fig. 5. 3D Finite element models](image)

Table 3. Information of 3D Finite element models

<table>
<thead>
<tr>
<th>Type</th>
<th>Hexahedron (Solid186, Solid187)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes</td>
<td>33,795</td>
</tr>
<tr>
<td>Elements</td>
<td>25,134</td>
</tr>
</tbody>
</table>

2.5 Boundary Condition of Compression Analysis

Compressive analysis was conducted by applying the characteristics of shape recovery of the femur models with the bone fixation grip; fixed support was set to the femoral distal part; then a force of 750N, the average body weight of Koreans was applied to the proximal part (Fig 6).

![Fig. 6](image)
2.6 Boundary Condition of Torsional Analysis

The torsional analysis was conducted by applying the characteristics of shape recovery of the femur models with the bone fixation grip; fixed support was set to the femoral distal part; then a torque of 12N-m [14], the physiological torque of the human thigh was applied to the proximal part (Fig 7).

3 Results

3.1 Results of Compression Analysis

Compressive analysis found 36.56MPa (von-Mises Stress) in the femur (Fig 8), along with 1.39mm directional displacement to the compression direction (Fig 9). Displacement due to compression force was analyzed. Additionally, the strain graph result indicates that the shape memory alloy has the effects of shape memory.
3.2 Results of Torsional Analysis

The torsional analysis found 37.76MPa (von-Mises Stress) in the femur (Fig 11) along with 0.42mm total displacement (Fig 12). Displacement was due to the torque that was analyzed. Additionally, the strain graph result indicates that the shape memory alloy has the effects of shape memory
Conclusion

In this study, the bone fixation grip manufactured by shape memory alloy has been investigated to overcome the disadvantages of the conventional bone fixation plate and screw system. Compressive analysis found that the femur model which includes shape memory alloy grip tolerates the loaded human weight and maintains its location. In the torsional analysis, the performance indicated that the shape-memory-alloy fixation grip fulfilled its role when torsion was applied to the femur model with the bone fixation grip.

In future studies, according to the commercialized fixation and screw system, finite element analysis will be implemented to analyze the compressive and torsional analysis. Through the comparison between the fixation plate-screw system and shape memory alloy grip with finite element analysis, stability of shape-memory alloy fixation grips will be investigated.

References

1. Statistics Korea, 2006; 2007 (In Korean)