An Optimization Study of Screw Position and Number of Screws for the Fixation Stability of a Distal Femoral Locking Compression Plate Using Genetic Algorithms

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ABSTRACT

A distal locking compression plate (DLCP) has been used to treat distal femoral fracture. An DLCP with a large number of screws can improve fixation stability, but the use of a small number of screws can reduce the damage on soft tissue and bone. The purpose of this study was to determine the best screw position and number of DLCP screws for distal femoral fracture fixation. Three-dimensional finite element models of the spine-pelvis-femur complex were developed to evaluate the fixation stability. The best screw position and number of DLCP screws were determined using a simulation-based genetic algorithm. The results showed that the DLCP with eight screws had acceptable fixation stability. The best screw position of the DLCP was four DLCP screws on either side of the bone fragment with three DLCP screws as close as practicable to the fracture site.

KEYWORDS

Distal femoral fracture, locking compression plate, finite element analysis, genetic algorithm.

1 INTRODUCTION

A minimally invasive plate osteosynthesis technique has been used to treat distal femoral fracture [1]. Distal locking compression plates (DLCPs) have several screw holes and can allow orthopedic surgeons to use different numbers of DLCP screws and to insert DLCP screws in different position [2]. In clinical practice, an DLCP with a large number of screws can improve fixation stability, but the use of a small number of screws can reduce the damage on soft tissue and bone. Past studies have discovered the screw numbers and positions using in-vivo experiments, in-vitro experiments, and/or numerical calculations [3]. However, these studies mostly determined the screw positions based on the experience of researchers [4]. We propose that applying evolutionary algorithms to solve this clinical problem should outperform existing methods for positioning screws in a DLCP. In this study, three-dimensional finite element models of the spine-pelvis-femur complex were created to analyze the fixation stability of different treatment strategies. The best DLCP screw positions and numbers of DLCP screws were determined using a simulation-based genetic algorithm. Thus, the aim of this study was to efficiently discover the best DLCP screw numbers and positions for the treatment of distal femoral fracture.

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2 MATERIALS AND METHODS

The solid model of the intact spine-pelvis-femur complex was scanned from a healthy volunteer. This model consisted of the lumbar spine (L3-L5), sacrum, left pelvis, pubic symphysis, and left femur. To simulate the injured situation, a transverse distal femoral fracture with a fracture gap of 5 mm was created. An DLCP with sixteen screw holes was used to treat this fracture (Fig. 1). All the solid models were constructed and modified using SolidWorks 2015 (SolidWorks Corp., Concord, MA, USA).

To construct finite element models, all treated spine-pelvis-femur models were imported into ANSYS Workbench 18.2 (ANSYS, Inc., Canonsburg, PA, USA). The material properties used in the present study were obtained from a past study [5], and a linearly elastic isotropic material was assumed. Due to complicated bone and implant geometries, the solid models were free-meshed using 20-node solid elements of SOLID 186, and a convergent study was conducted by increasing the mesh density. In the loading and boundary conditions, a body weight of 400 N was applied to the top surfaces of the L3 vertebra, and the distal surfaces of the femur were fully constrained (Fig. 1). In post-processing, the directional deformation was calculated to investigate the fixation stability of different fixation strategies.

In design optimization of the screw numbers and positions, the objective function was to minimize the directional deformation of the fractured model treated with the DLCP. The design variables were the DLCP screws which were either absent from or present in the DLCP. One screw was absent from the sixteen-hole DLCP on the screw hole near the fracture site. Thus, fifteen design variables (From DV_1 to DV_{15}) were defined in this study (Fig. 1). To convert a continuous value of each design variable, a ranked-order value algorithm was used to determine a ranking of all design variables [6]. A design variable with higher value had higher priority to insert DLCP screw. In this study, the design range of the design variables was from zero to one. The constraints of the optimization study included the number of DLCP screws, the number of DLCP screws inserted into the proximal fragment, and the number of DLCP screws inserted into the distal fragment. It is important that the number of DLCP screws inserted into each bone fragment should be greater than or equal to one to avoid any infeasible treatment. The simulation-based genetic algorithm was developed and coded with the use of the ANSYS® Parametric Design Language (APDL) to solve this optimization problem (Fig. 2). The uniform point crossover rate and the single point mutation rate were 90% and 1%, respectively. Each population had twenty designs, and each design variable had five strings. The optimization stopped when the objective value of the last ten iterations was equal.

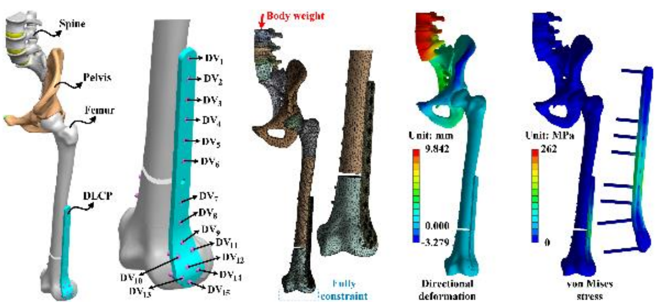

Figure 1: The definition of the design variables and the numerical model of the spine-pelvis-femur complex.

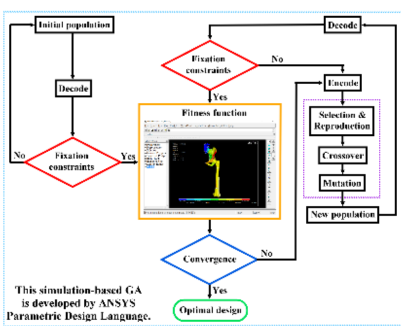

Figure 2: The flowchart of the simulation-based genetic algorithms.

3 RESULTS AND DISCUSSIONS

All the finite element models were successfully solved, and the error caused by the mesh density was less than 3%. After the stopping criterion was reached, the simulation-based genetic algorithm discovered the optimal positions in situations with different numbers of DLCP screws. The optimal positions were 1-6-7-15 for the DLCP with four screws, 1-5-6-7-8-15 for the DLCP with six screws, 1-4-5-6-7-8-9-15 for the DLCP with eight screws, 1-3-4-5-6-7-8-9-10-15 for the DLCP with ten screws, and 1-2-3-4-5-6-7-8-9-10-11-15 for the DLCP with twelve screws. The insertion of DLCP screws into suitable positions of DLCPs can achieve the required fixation stability. However, DLCPs with inappropriate screw position might results in poor fixation stability. In this study, eight DLCP screws inserted into the DLCP at inappropriate screw positions (1-2-3-4-5-6-14-15) had lower fixation stability (larger directional deformation) than four DLCP screws inserted into the DLCP at optimal screw positions (1-6-7-15) (Fig. 3).

The results of different number of DLCP screws showed that the fixation stability of the DLCP with four screws was significantly inferior to that with eight screws. However, there was no significant difference between the DLCP with eight screws and fifteen screws (Fig. 3). It means that the DLCP with eight screws can achieve the required stability for the sixteen-hole DLCP.

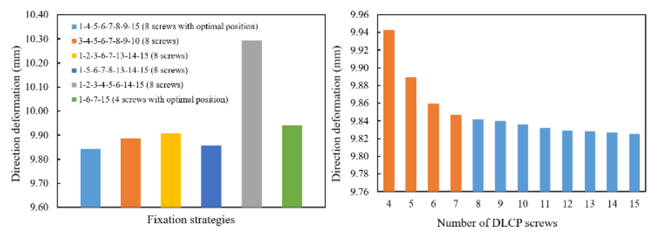

Figure 3: The directional displacement of the DLCPs with different screw positions and numbers.

4 CONCLUSIONS

This study successfully discovered the best number of DLCP screws and DLCP screw position for the treatment of distal femoral fracture using the simulation-based genetic algorithm. The DLCP with eight screws had the acceptable fixation stability. Additionally, the best screw position of the DLCP was four DLCP screws on either side of the bone fragment with three DLCP screws as close as practicable to the fracture site.

ACKNOWLEDGMENTS

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