Journal ARTICLE

A Theoretical Finite Element and Biomechanical Analysis of Transpedicular Screws for Fixation of the Spine

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Introduction:

The choice of a transpedicular bone screw for fixation of the spine is made difficult by the variety of screws available which differ in material properties, dimensions and geometry. Above all, the choice is made difficult by a lack of scientific analysis on the bending strength, fatigue characteristics, stiffness and pull-out strength with respect to the above variables. The purpose of this study is to develop and validate a theoretical Finite Element Analysis (FEA) model where the dimensional and geometrical properties can be independently varied, allowing for optimization of a screw design with respect to bending stiffness and pull-out strength. FEA enabled evaluation of the following variables independent of material and manufacturing variances: A) Pitch of 2.8, 2, and 5mm (Figure 1) ; B) Ratio between minor and major diameter (RMM) of 44, 25, and 75% (Figure 2) ; C) Taper over length of minor diameter of 0.05, and 100% (Figure 3). These variables were evaluated both experimentally and using FEA with respect to bending stiffness and pull-out strength.

Fig. 1

Fig. 2

Materials and Methods:

A standard 6.5 x 40mm 316L stainless steel (ASTM F138) AO bone screw was used as a control model, and material and mechanical properties for 316L were used for all models. The AO screw variables were 2.8mm pitch, 44% RMM, and 0% taper. First, a three dimensional (3D) FEA model of the AO screw was constructed and load stepped under cantilever bending to generate a force vs. displacement graph, from which stiffness was calculated (Figure 4) , and a stress plot was produced to pinpoint the areas of highest stress (Figure 5). This model was validated experimentally by testing six (6) AO screws (Figure 6) under load control to generate six independent stiffness values, which were then averaged and compared to the FEA value. The remaining variables were evaluated in the same manner. Next, a two dimensional (2D) FEA model of the AO screw was constructed for the pull-out strength, along with a simulated cancellous bone block. As a result of the 2D modeling, direct biomechanical comparison and validation of absolute pull-out force was not possible. However, six (6) AO screws were tested for pull-out (Figure 7) , along with samples produced to evaluate the remaining variables. If the statistical rankings of the FEA pull-out models matched the rankings of the experimental testing results, even though the specific values were not equal, the FEA model for pull-out was considered validated.

Fig. 3

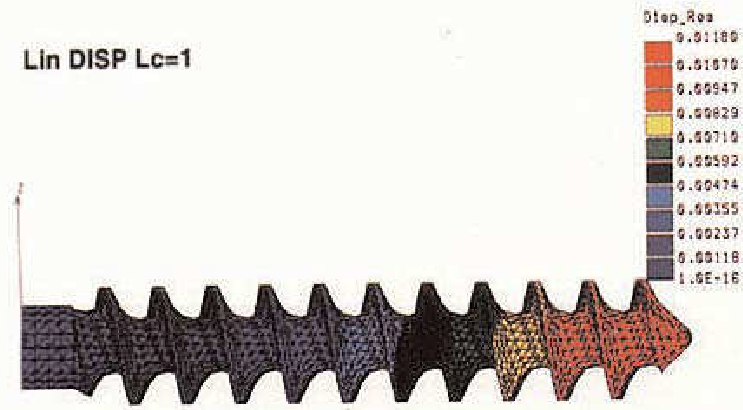

Fig. 4

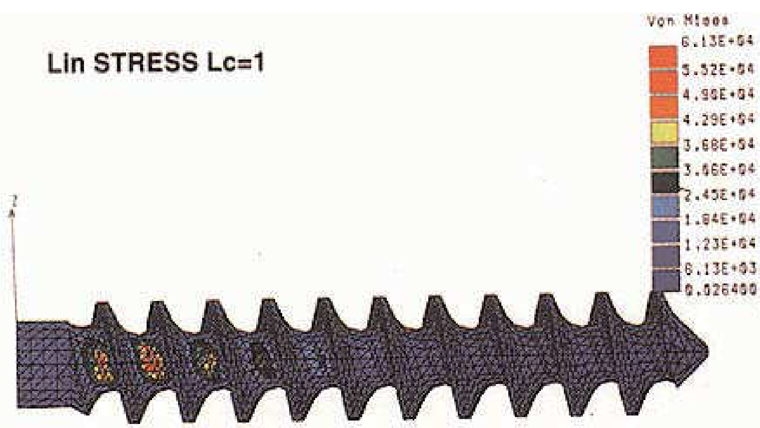

Fig. 5

Results:

Comparing the theoretical FEA and experimental stiffness values in cantilever bending for all variables yielded differences ranging from 0.7 to 22% (Figure 8) , validating the FEA model. The percent difference between the lowest and highest values for all variables was 2250% (Figure 8) . Statistical analysis showed that no differences exist between the three pitches, but that differences do not exist between the three RMM's and the three tapers.

Comparing the theoretical FEA and experimental values for pull-out showed identical rankings for all variables, validating the FEA model. The percent difference between the lowest and highest values for all variables was 44% (Figure 9). Statistical analysis showed that differences exist between the three tapers.

Conclusions:

The results indicate that changing the variables of pitch, RMM and minor diameter taper affects the bending stiffness of the screw much more dramatically than it affects the pull-out strength. The pitch and RMM of the control screw are in the optimal range, but adding a minor diameter taper significantly improves the bending stiffness without sacrificing pull-out strength. Based on this study, optimum screw design relative to bending stiffness and pull-out strength is the 50 or 100% tapered screw. Of equal importance, further optimization can be readily performed using these validated FEA models.

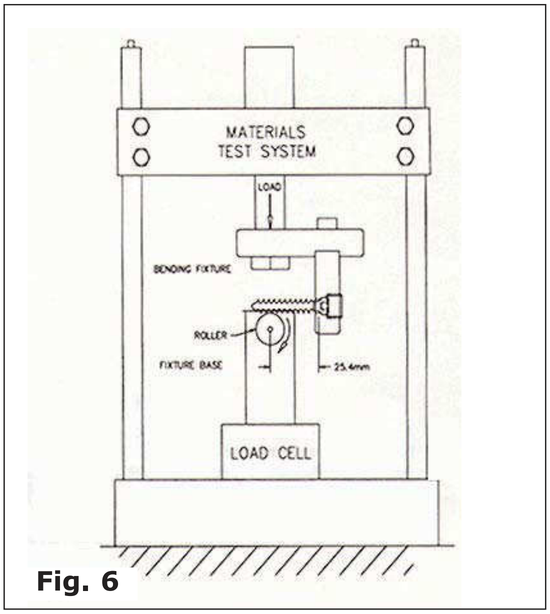

Fig. 6

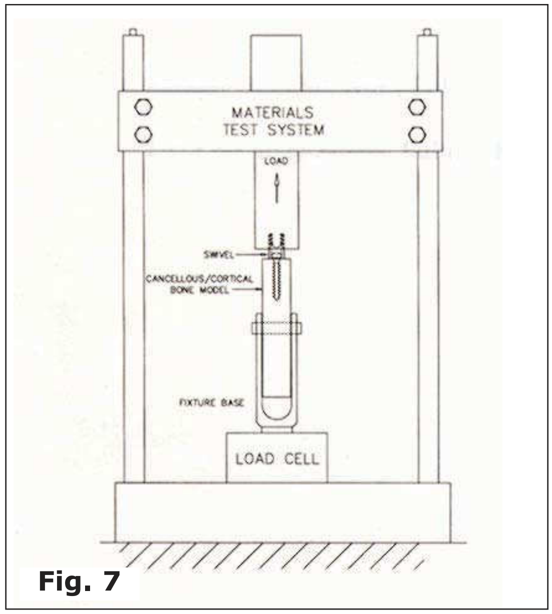

Fig. 7

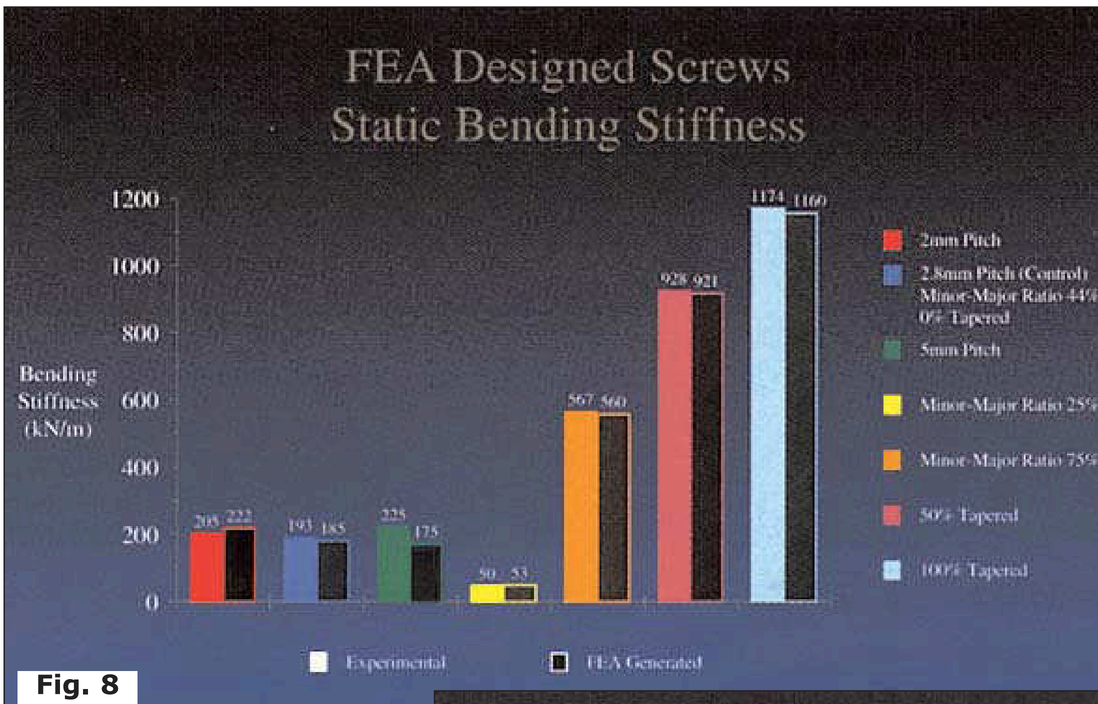

Fig. 8

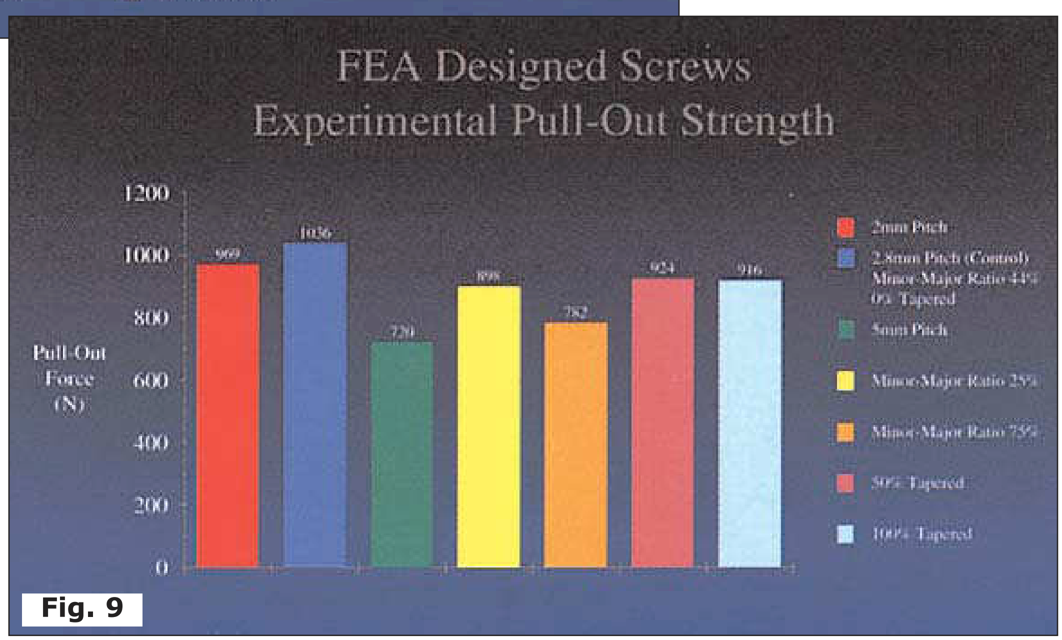

Fig. 9