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Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Corrective Force Analysis in Spinal Rods Fixation for Scoliosis Deformity

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INTRODUCTION:

Scoliosis is a serious disease in which a human spine is abnormally deformed in three dimensional (3D) directions with vertebrae rotations. The effective surgical treatment of severely curved scoliotic spine is achieved through fixation of spinal rods to modify the spine geometry by applying the suitable corrective forces. The spinal rods work to support the various loads generated by spine deformity corrections and skeletal motions. The measurement of forces acting on the spine and the implants in vivo is important to evaluate the scoliosis treatment and to prevent bone and implant fracture [1]. It is difficult to measure the forces applied to the spine structure in vivo. For a diseased spine corrected with the rods, load distribution applied to the spine after treatment could be estimated by detecting the deformation occurred on the implanted rods. In this study, a force analysis method using finite element (FE) analysis from the deformation of implanted rod detected by 3D imaging after scoliosis treatment is proposed to estimate in vivo forces acting on the spine. This analysis was applied to the spinal rods in actual scoliosis treatments to evaluate the scoliosis corrective force after the surgical treatment.

METHOD:

Figure 1 shows the procedure of force analysis. The analysis requires the geometry change of spinal rod and loading points on the rod. The rod geometry and loading condition were obtained in the 3D imaging. The 3D FE model is constructed from the rod geometry before treatment. Deformed rod geometries are simulated by FE analysis under the arbitrary loadings at the fixation positions corresponding to the spine vertebra. Forces were applied to the given geometry after surgical treatment. These forces were calculated by iteration process. The error function in the iteration process was defined as the difference of displacement of the simulated geometry and given geometry measured after surgical treatment. The forces were iterated until the errors were minimized.

ANALYSIS FOR SCOLIOSIS TREATMENT:

The change in geometry of the spinal rod was measured before and after surgical treatment [2]. Initial shape of the rod could be directly measured before the surgical implantation. Deformed shape of the rod was obtained by X-ray CT measurement after the scoliosis treatment. The loading positions were set at the fixation points of the rod. Locations could be determined from the screws positions in the CT image. Figure 2(a) shows the CT image of a spine after the surgical treatment. A rod was fixed at T6, T7, T11 and T12 of thoracic spine vertebrae as shown in Figure 2(b).

The rods of 6 mm diameter were used in the treatment. The length obtained between the two extreme supports (T6 to T12) was 159 mm. A FE model was created using beam elements and analysis was performed using a FE analysis software (ANSYS ver 11.0). The boundary condition of point T12 was set to be fixed in all directions, but free to rotate. The point T6 was free to move along spinal axis direction only. The elastic-linear plastic material property was assumed. The rod material was set as a pure titanium having elastic modulus, yield stress, ultimate stress, ultimate strain and Poisson's ratio of E = 105 GPa, σ_y = 485 MPa, σ_u = 550 MPa, ε_u = 0.15, and ν = 0.3 respectively, considered to be ASTM Grade 4 titanium. The forces were acting at the four fixed positions through the screws.

RESULT:

The forces were iterated until the displacements errors were almost zero. Figure 2(b) shows the forces acting at the support points on the rod when the rod was deformed from before to after the surgical treatment. The displacements of fixation positions and the corresponding forces are shown in Figure 3. Relatively high forces were found at the vertebra locations of T11 and T12. The analysis presented here consists of deformation of the rod after the surgical treatment.

DISCUSSION:

This analysis can be applied for some scoliosis treatments that include implant rod deformation. The accuracy of current force analysis method is dependent on the resolution of 3D imaging in vivo. The bending stress directly related to the curvature of the deformed rod. The result of this analysis includes the modeling error. In actual case, the rod was plastically bent initially. The work hardening and the load history should be considered for precision analysis if plastic deformations were repeatedly occurred during the scoliosis treatment.

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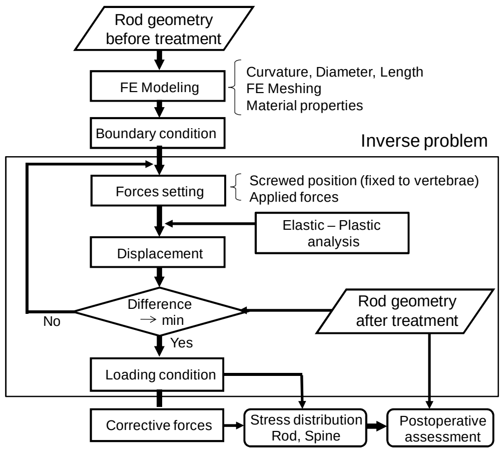

Figure 1 Force analysis process using rod geometry change

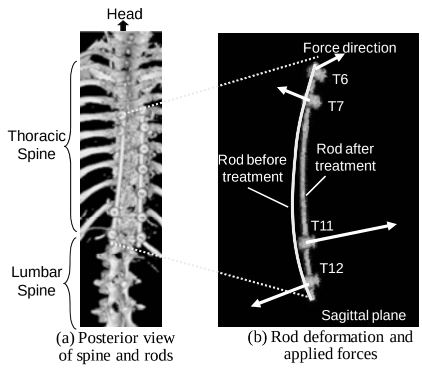

Figure 2 Forces acting to spinal rod in scoliosis treatment

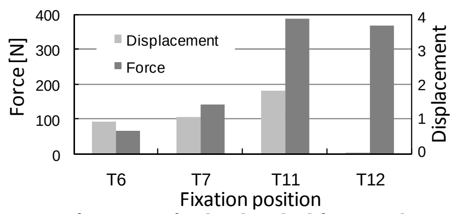

Figure 3 Deformation of rod and applied forces in the treatment