B217 脊柱側弯症矯正中の固定ロッドに作用する力

Force analysis of corrective rod for scoliosis treatment

○正 サルミンゴ・レメル (北大院) 正 藤崎 和弘 (北大)
正 但野 茂 (北大) 非 安倍 雄一郎 (北大医)
非 伊東 学 (北大医)

Remel SALMINGO, Kazuhiro FUJISAKI, Shigeru TADANO
Division of Human Mechanical Systems and Design, Graduate School of Engineering, Hokkaido University

Yuichiro ABE, Manabu ITO
Department of Orthopaedic Surgery, Graduate School of Medicine, Hokkaido University

Key Words: Scoliosis, Implant deformation, Corrective force, Finite Element Analysis

1. INTRODUCTION

Scoliosis is a serious disease in which a human spine is abnormally deformed in three dimensions with vertebral rotation [1]. Surgical treatment for scoliosis is attained by applying suitable corrective forces so as to deform the scoliotic spine into the frontal straight line using implant rods fixed at the vertebrae by screws. Analysis of the corrective forces is important to prevent bone and implant fracture [2]. The implant rod made from titanium was used as a force sensor in vivo. A method based on non-linear Finite Element Analysis (FEA) was developed to calculate the corrective forces occurring on each fixation position from the changes of implant rod geometry before and after the surgery.

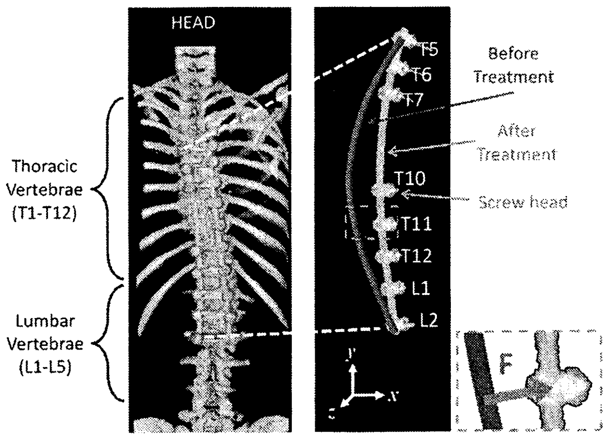
2. METHODS

The changes in the geometry of rod before and after the surgical treatment were obtained from the corresponding displacements of every fixation point (screws). The applied forces occurring on each screw that deformed the rod were calculated by FEA using the displacements. Conversely, the opposite of the applied forces are the corrective forces that deformed the spine after the surgical treatment. Figure 1(a) shows the CT image of the spine after the surgical treatment. In this case, the applied forces were located at T5, T6, T7, T10, T11, T12, L1 and L2 of the deformed rod in Fig. 1(b).

The procedure for corrective force analysis is shown in Fig. 2. Firstly, the initial geometry of rod before and after the surgical treatment was obtained. The finite element model was created and the boundary conditions were applied. Forces were then applied to the geometry before the treatment through the corresponding locations of screws obtained from the geometry of rod after the treatment. An elasto-plastic analysis was performed. The applied forces were iterated until the difference between the displaced model and the geometry of rod after the treatment was minimized. The corrective forces were obtained from the applied forces.

3. ANALYSIS OF SCOLIOSIS CASE

The corrective forces acting at the vertebrae of the three scoliosis cases were calculated using the method described above. The implant rods of 6mm diameter were used in the surgical treatment. The initial geometry of the rod was measured from the actual rod used before the surgery. The final geometry of rod was measured by CT imaging after the treatment. The total length of rod and the distance between the support points were measured using CAD software (Solidworks 2009). Analysis was performed using FEA software (ANSYS ver 11.0). FEA model was created using a 10 node tetrahedral element.



(a) Posterior view of the spine and rods fixed by screws (b) Deformed rod and force occurring at fixation point

Fig. 1 Image showing implant rod deformation before and after the surgical treatment

The boundary condition of point L2 was fixed but free to rotate the same with point T5 except that it was free to move along y-axis only. The rod material presented in Table 1 was elastic-linear plastic model expressed using the equations below:

$$\sigma = E\varepsilon \quad \{0 < \varepsilon < \varepsilon_Y \text{ ; elastic region} \tag{1}$$

$$\sigma = \sigma_Y + E_T(\varepsilon - \varepsilon_Y) \quad \{\varepsilon_Y < \varepsilon < \varepsilon_B \text{ ; plastic region} \tag{2}$$

Table 1 Material Properties (Pure Titanium)

Elastic Modulus (E)	105 GPa
Yield Strength (σ_Y)	485 MPa
Ultimate Strength (σ_B)	550 Mpa
Ultimate Strain (ε_B)	0.15
Poisson's Ratio (v)	0.3

4. RESULTS AND DISCUSSION

The applied forces were iterated until the difference between the displaced model and the geometry of rod after the treatment was minimized. Figure 3 shows the corrective forces acting at the corresponding vertebra of each scoliosis case. The maximum values of corrective forces were 203 N, 215 N and 333 N for Case 1, Case 2 and Case 3 respectively. The FEA analysis presented here was focused only to the magnitude of corrective forces that deformed the rod after surgery. The effect of these corrective forces to the stress distribution of the vertebral bone, rod and screws shall be further investigated.

Information about the corrective forces acting on the spine is important to develop a new method of corrective treatment for scoliosis. In this study, the distributions of corrective forces were analyzed. The method was used to calculate the corrective forces of scoliosis case using just the rod geometry before and after the surgical treatment.

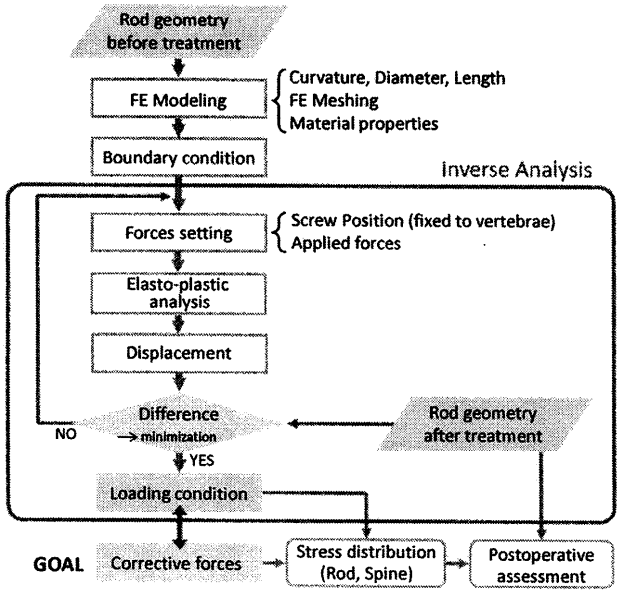


Fig. 2 Procedure for corrective force analysis

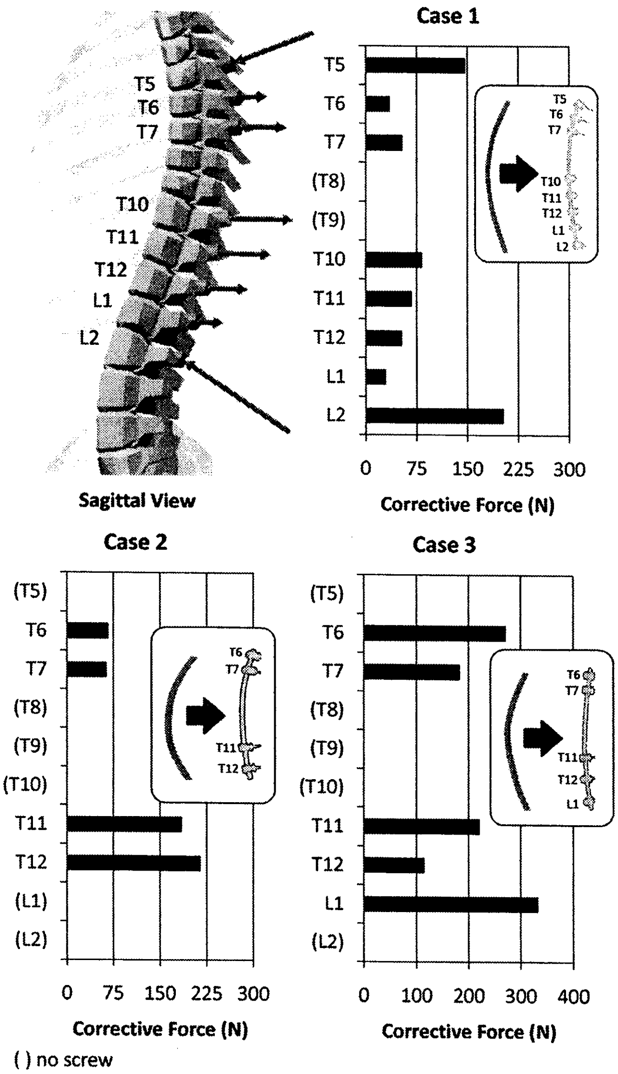


Fig. 3 Corrective forces distribution occurring at each vertebra of the scoliosis cases

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