Study on Classification of Clinical Deformities Based on Hypothesis of Mechanical Etiology for Idiopathic Scoliosis

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Introduction

Scoliosis is known as a disease that causes abnormality in a physiological curvature of the spine. In the scoliosis, idiopathic scoliosis is classified as a spinal irregularity with lateral curvatures without any remarkable abnormality in vertebrae or associated musculoskeletal systems.

Recently, a trial to investigate a mechanical etiology by using the finite-element method was begun. By growth deformation and buckling analyses with a finite-element model of the spine, Azegami et al. presented a hypothesis that idiopathic scoliosis is a buckling phenomenon of the fourth or sixth mode induced by the growth of vertebral bodies.

Based on the hypothesis, Takeuchi et al. presented that it is able to find the most effective reinforcement parts to delay generating the buckling modes by applying a shape optimization theory. Their numerical results explained some practical rules known in clinical field. In addition, Sasaoka et al. developed a morphing technique that involves selecting nodes on a finite-element model and moving them to desired locations under suitable constraints in reference to clinical image data such as X-ray photographs or CT data.

Applying their techniques, it can be considered to construct finite-element models of the spine for individual patients using the morphing technique, to analyze the buckling modes induced by the growth of vertebral bodies in the normal spine model varying growth parts, and to identify the growth patterns for individual patients by calculation of the coefficients of correlations between clinical deformities and the representative buckling modes. If the individual growth patterns could be identified, it can be expected to estimate natural history, to identify the most effective reinforcement parts, and to predict process after treatment. In this study, a trial to identify the growth patterns using clinical data was examined.

Method

Clinical deformities were constructed with the developed spine finite-element model by the morphing method using X-ray photographs. Besides, the representative buckling modes were analyzed using the normal spine model for 49 growth patterns in similar to Takeuchi et al. In this study, the cervical vertebrae C2 to C7 were constrained without vertical movement because the cervical vertebrae of the clinical data were kept in the normal position. Hence, the fourth and sixth modes do not correspond to the single and double curves. The coefficients of correlations ρ were calculated by the finite-element method for the domain $\Omega \in \mathbb{R}^3$ of the normal spine model with inner products between the displacements of the finite-element model with clinical deformities $u : \Omega \mapsto \mathbb{R}^3$ and the representative buckling modes $v : \Omega \mapsto \mathbb{R}^3$ as follows.

$$\rho = \frac{(u, v)_{L^2(\Omega)}}{\sqrt{(u, u)_{L^2(\Omega)}} \sqrt{(v, v)_{L^2(\Omega)}}} \quad (1)$$

$$\int_{\Omega} u \cdot v \, d\Omega \quad (2)$$

Result

Figures 1 and 2 show X-ray photographs, constructed model with clinical deformities using the morphing method, and the best fitted buckling modes. For the case with single curve, the second mode by the growth of the vertebrae T5 to T11 had the highest coefficient of 0.964. For the case with double curves, the third mode by the growth of the vertebrae T3 to L3 had the highest coefficient of 0.658.

From the results, a consideration shown by Takeuchi et al. was demonstrated that cases with single curve are generated by growth of limited vertebrae and cases with double curves are generated by growth of wide vertebrae.

Conclusion

The possibility was presented to identify the growth patterns for individual patients by calculating the coefficients between the displacements of the finite-element model with clinical deformities and the representative buckling modes.