学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Biomechanical Approach on Corrective Force Acting on Spine in Scoliosis Deformity Surgery
(脊柱側湾症矯正術によって脊椎に作用する矯正力に関するバイオメカニクス的研究)

Scoliosis is a complex pathology characterized as a three-dimensional (3D) deformity of the spine combined with rotation of the vertebrae. The treatment for severe scoliosis is achieved when the abnormally deformed spine is surgically corrected and fixed into a desired shape by application of corrective forces using implant rods and screws. Understanding the magnitude of corrective forces carried by the implant rods is important because overloading can lead to implant rod and bone fracture. The deformation of implant rod is an inevitable consequence of the corrective forces developed by the inherent resistance of the scoliotic spine to correction. The main aim of this study was to analyze the scoliosis corrective forces from implant rod deformation using Finite Element Analysis. The changes of implant rod geometry before the surgical implantation and after surgery were measured to analyze the postoperative corrective forces. A numerical method to measure the intraoperative three-dimensional geometry of implant rod and rod deformation using two cameras is proposed. The intraoperative deformation of implant rod during scoliosis corrective surgery was measured by the dual-camera system and consecutively the intraoperative forces using the proposed method based on Finite Element Analysis. The effect of screw placement configurations, i.e. number of screws and screw density to the corrective forces and degree of scoliosis correction was also investigated. The postoperative corrective forces acting on the vertebrae of the spine were significantly lower than the intraoperative corrective forces. The increase in number of screws tended to decrease the magnitude of corrective forces but did not provide higher degree of scoliosis correction. Although higher degree of scoliosis correction was achieved with higher screw density, the corrective forces increased at some levels indicating that higher screw density is not guaranteed as the optimal surgical strategy. Scoliosis correction is not only dependent on the corrective forces but also with various parameters such as screw placement configuration and implant rod shape.

Chapter 1 briefly introduces the background of the study. The previous studies section discusses the related literatures on corrective forces acting on the implant rod and spine during the scoliosis treatment and the delimitations in relation to the current level of research in the area. The main objectives of this study are also presented.

Chapter 2 provides a general background, biomechanical and clinical aspect of scoliosis as a disease. This chapter presents also the principles of management of scoliosis, i.e. how it is being treated by implant fixation, and the existing problems in which this research study is trying to address from a biomechanics point of view.

Chapter 3 presents a method to analyze the corrective forces acting on the implant rod and vertebra using finite element modeling. The implant rod before the surgical implantation was reconstructed using an elasto-plastic finite element model. This chapter also presents the three preliminary clinical cases that were used to conduct finite element deformation analysis.

Chapter 4 deals with the development of a dual-camera system and numerical method to measure the three-dimensional implant rod geometry intraoperatively for scoliosis deformity surgery. The results of the validation experiment to establish the accuracy of the dual-camera system using the actual implant rod utilized during scoliosis surgery are presented.

Chapter 5 presents the effect of various screw placement configurations on the magnitude of corrective forces and degree of scoliosis deformity correction. This chapter discusses the consequences of using more screws and putting screws nearer to each other (screw density) to the magnitude of corrective forces and degree of scoliosis correction. The magnitude of forces did not have significant relationship with the degree of scoliosis correction. The corrective forces tended to reduce when more screws were used indicating that the loads acting on the spine were more distributed. The magnitude of corrective forces increased with higher screw density.

Chapter 6 presents the deformation behavior of implant rod using the changes of implant rod geometry before surgical implantation and after surgery. The influence of the changes of implant rod curvature on scoliosis correction was also presented. A significant relationship was found between the degree of rod deformation and implant rod curvature before surgical implantation indicating that the rod curvature after surgery or the clinical outcome could be predicted from the initial implant rod shape. The changes of implant rod curvature greatly influenced the scoliosis correction because the spine curve can be over or under corrected after scoliosis surgery.

Chapter 7 deals with the clinical application of the dual-camera system to measure the intraoperative three-dimensional geometry of implant rod during scoliosis surgery. The three-dimensional geometry of implant rod at the different phases of scoliosis treatment (i.e. preoperative, intraoperative and postoperative) was measured. The intraoperative forces were also computed.

Chapter 8 summarizes the findings and conclusions of the work, their clinical and biomechanical significance is also discussed.

The work presented in this thesis provides clinicians and bioengineers a new method to measure the magnitude of corrective forces acting on the vertebrae of the spine and implant rod using finite element modeling. The dual-camera system that has been developed gives in-depth insights on the deformation behavior of implant rod at the different phases of scoliosis treatment, i.e. from preoperative, intraoperative, and postoperative phases. The effects of screw placement configuration to the magnitude of the corrective forces and degree of correction will help clinicians to objectively decide which surgical strategy is likely to attain a desirable outcome. The deformation behavior of the implant rod observed in this study revealed that the postoperative implant rod geometry could be predicted from the initial implant rod shape. This is essential for the preoperative planning of the surgical parameters such as decision-making of the initial implant rod geometry. This study brings forward new insights on the effects of spinal instrumentation to the biomechanics of scoliosis correction.