Biomechanical analysis of plasma treated NiTi materials for spinal deformity correction

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Introduction: Scoliosis is the abnormal lateral curvature of spine and may lead to early back pain and cardiopulmonary compromise as condition deteriorates. Surgery will be considered in severe cases. However, the current techniques can only achieve 60-70% correction due to the visco-elastic properties of spinal tissues. Hence, nitinol has been developed to overcome these problems by using the shape memory and superelastic properties. Nevertheless, its nickel concentration is a major clinical concern. Previously, we successfully demonstrated the Ni suppression on superficial layer by plasma surface treatment. This study aims at determining the biomechanical properties of the plasma-treated nitinol spinal rods.

Methodology: The samples were treated at 800°C 1 hour with furnace cooling, 450°C 30 minutes with water quenching and followed by nitrogen plasma immersion ion implantation at 40kV for 4 hours. The rods embedded with spinal functional unit were undergone static and dynamic compressive bending tests under temperature control according to ASTM F1717-01. Five models were used in the static test. For the dynamic test, two models were used for each of the three loading levels (75%, 50% and 25% of ultimate load). The fatigue strength was equal to the loading level with two models endured five million cycles without failure.

Results and Discussion: All samples were plastically deformed without failure after the static test. The average ultimate load was equal to 516.2 N (SD = 18.1 N). For the dynamic test at 75%, there was unilateral fracture of nitinol rod in each model after half million cycles. Bilateral fracture near the rod and screw junction in both models was occurred at 50% after million cycles. The last two models were loaded for over five million cycles without failure at 25%. The fatigue strength was equal to 25% ultimate load, i.e. 129.0 N. Since there is no minimum strength limit stated in the ASTM standard, the biomechanical properties of new implant can only compare to existing implant system with satisfactory result. Stand et al. also followed the guideline in ASTM standard to study the biomechanical properties of spinal implant. The reported ultimate load of six different implant designs ranged from 292 N to 663 N and all six designs lasted for five million loading cycles at 25% ultimate load. Therefore, with the average ultimate load in this study equal to 516.2 N. The nitinol spinal rod has similar biomechanical properties to the existing systems.
Fig. 1 Vertebrectomy model with plastically deformed nitinol rods after static compressive bending test.

Fig. 2 Setup of compression testing for the whole spinal system with nitinol rods.

Fig. 3 Semi log diagram of maximum load versus number of cycles to test termination.

Conclusion: This biomechanical testing has demonstrated that the fatigue property of our nitrogen plasma treated NiTi spinal rods is comparable to the existing implants and therefore it can be considered for further clinical trial.

Reference:

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