APPLICATION OF REDUCED ORDER MODELLING TECHNIQUES FOR STRESS ANALYSIS IN SPINE FIXATION

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Introduction

The posterior pedicle screw fixation is a widespread surgical treatment of vertebral fractures [1]. Loosening and failure of screws are complications that could result in loss of correction and kyphosis [2]. Experimental and numerical studies showed that the diameter of screws is predominant in influencing the stability of the instrumented spine after the surgery [3]. The effect of the diameter can be studied numerically by means of computed tomography (CT)-based finite element (FE) models. Nevertheless, parametric modelling is based on time-consuming workflows and can be used to test only some configurations of the diameter within the range of variation. The goal of this study was to use a reduced order model (ROM) based technology to estimate local mechanical quantities continuously in the range of variation of the parameters. A mesh morphing pipeline to build a parametric model with consistent meshes suitable to the application of the method was needed.

Methods

The pre-operative CT-scans of the thoracolumbar spine of three anonymized patients were processed to obtain the geometry of three lumbar vertebrae (L2, L3, L4). Two simplified pedicle screws (no thread, diameter D=6.5mm, length L=45mm) were inserted by a Boolean subtraction in the vertebrae. Two methods were used to change the diameter of the screws from 5.5mm to 7.5mm: a traditional computer aided design (CAD)-based workflow and a mesh morphing based one with RBF Morph™ [4]. Subject-specific FE models were used to simulate a quasi-static compressive load virtually transmitted through the rods to the head of screws (100N vertical load on each screw). The inferior endplate was fixed in the three directions. Both bonded (linear) and contact conditions (nonlinear, friction μ=0.3) at the screw-vertebra interface were tested. The Ti-6Al-4V screw was simulated as homogenous linear elastic material (E=102GPa, ν=0.36) and the bone as heterogeneous linear elastic material (E as function of the bone mineral density, ν=0.3). 10-nodes, 1.0mm size tetrahedrons were used for the bone and 20-nodes, 0.6mm size hexahedrons were used for the screws [5]. The max deflection (d_{max}) of the head of the screws and the max von Mises stress (σ_{VMmax}) of the screws were compared for models obtained with the traditional workflow or the morphing pipeline. A ROM of the deflection (d) and a ROM of the von Mises stress (σ_{VM}) on the screws were built with Ansys Static ROM Builder, for both linear and nonlinear models. The results from models with D=5.5, 6.5 and 7.5mm were used as training, while the results from models with D=6.0 and 7.0mm were used as validation. The maximum relative ROM error was reported.

Results

The average difference in d_{max} between standard and morphed models was lower than 1% and 4% for the linear and nonlinear cases, respectively (Table 1). The average difference in σ_{VMmax} was lower than 1% and 5% for the linear and nonlinear cases, respectively. The average maximum relative ROM error in d was lower than 1% (linear) and 2% (nonlinear) (Table 2). The average maximum relative ROM error in σ_{VM} was lower than 2% (linear) and 3% (nonlinear).

D	% diff - d_{max}		% diff - σ_{VMmax}	
(mm)	Linear	Nonlinear	Linear	Nonlinear
5.5	0.7±0.3	3.5±2.4	0.9±0.7	4.3±0.5
6.5	0.0±0.0	0.4±0.4	0.8±0.4	1.3±0.5
7.5	0.6±0.2	1.3±0.3	0.4±0.3	4.8±0.3

Table 1: Differences (mean ± st dev) between morphing and remeshing.

D	Max % err - d		Max % err - σ_{VM}	
(mm)	Linear	Nonlinear	Linear	Nonlinear
6.0	0.6±0.2	1.5±0.2	1.7±0.5	3.0±0.6
7.0	0.4±0.1	1.3±0.4	1.1±0.2	2.6±0.8

Table 2: ROM error (mean ± st dev) compared to morphing approach.

Discussion

The results of the present study show that the deflection and the von Mises stress on the pedicle screws can be predicted for any given diameter between 5.5 and 7.5mm with good accuracy (average max error of about 5%). This approach will be used to optimize the size of the screws in a large cohort of patients in future studies.

References

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