UNCERTAINTY QUANTIFICATION COUPLED WITH FINITE ELEMENT SIMULATION OF THE SECOND STAGE OF LABOR

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Introduction

Finite element models of the pelvis system for labor and childbirth simulations have been commonly developed to analyze vaginal delivery mechanism leading to avoid potential complications (e.g. levator ani muscle injury) [1]. However, the reliability of the simulation outcomes remains a challenge due to complex pelvis system geometries and mechanical properties of the involved soft tissues. In particular, uncertainty quantification (UQ) of the input data and associated propagation effect is still not investigated. The objective of this work is to perform UQ of the material properties of the uterus soft tissues and to simulate its propagation during the second stage of labor simulation. In particular, dependent properties were modeled with specific uncertainty formulation.

Methods

A generic model of the soft tissues including floor muscle, the vagina, and the uterus was developed using a computer-aided design (CAD) process and *Blender* software (Fig. 1a). Then, the fetus body was meshed using Abaqus with 5877 C3D4 linear tetrahedral elements and the assembled uterus and floor muscle were meshed using 4974 C3D4 tetrahedral elements (Fig. 1b). To simulate the second stage of labor, the boundary conditions of the model are fixed at the top and bottom of the uterus (Fig. 1c). The simplified cardinal movement of the fetus was modeled by imposed displacement according to y and z directions (0,-45,-25) mm (Fig. 1c).

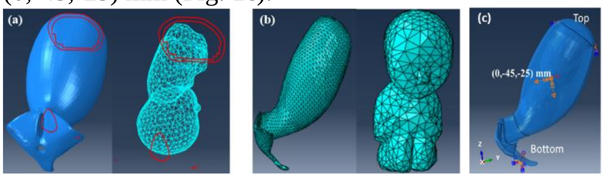

Figure 1: Soft tissue modeling: geometries (a), meshed models (b) and boundary conditions (c).

Soft tissues were modeled using Neo-Hookean hyperelastic formulation (C_{10} = 0.05 ± 0.01 MPa and D_1= 24 ± 5 MPa^{-1} for uterus tissue and C_{10} = 0.075 MPa and D_1= 0.77 MPa^{-1} for fetus tissue) [2]. To perform UQ, C_{10} and D_1 of the uterus tissue are considered as random variables with uniform distributions. The copula formulation was used to model the correlation between these variables. Then, a Monte Carlo simulation was performed using Python scripting within Abaqus environment. Maximum Von Mises stress on the uterus surface along a specific path was extracted for establishing the cumulative distribution function (CDF) as an UQ analysis metric.

Results

The displacement field of the uterus tissue along a specific path at the uterus neck during the UQ process is illustrated in Fig. 2.

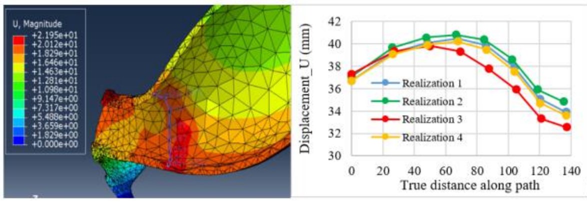

Figure. 2 Displacement field of the uterus tissue along a specific path at the uterus neck under different simulation trials.

A CDF of the maximal stress outcome is showed in Fig. 3. The copula-based analysis leads to the identification of 10% quantile (P10) and 90% quantile (P90) ranges of the maximal stress field.

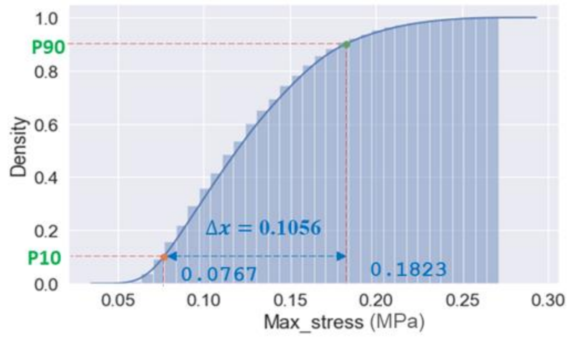

Figure. 3: CDF of the maximal stress field.

Discussion and Conclusions

Uncertainty quantification is one of the best practices in biomechanical modeling to ensure the reliability of the outcomes [3]. This study showed that material properties of the uterus soft tissue are sensitive to the simulation outcomes and their uncertainties should be taken into consideration. In particular, the use of copula allows dependent properties to be taken into consideration. As perspective, the active uterus behavior will be integrated into a more realistic second-stage labor model and simulation. Then, uncertainty quantification will be conducted for more reliable decision support.

References

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