Towards Male Specific Material Properties for Cervical Ligaments in Finite Element Human Body Models and its Validation in Functional Spine Units

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I. INTRODUCTION

The components of the human neck such as intervertebral discs, cervical vertebrae and especially cervical- and cranio-vertebral ligaments play an essential role in the kinematic response of finite element Human Body Models (HBMs). The strain rate dependent linear stiffness behaviour of a set of male and female cervical ligaments was characterized experimentally by [1, 2]. This study presents a new analysis by clustering only the male experimental data in order to create a male specific response corridor for cervical ligaments. A HBM was fitted with this new data. Flexion and tension [1-3] validation cases with functional spine units (FSUs) were simulated. The overall performance of the modifications was tested under [4] in order to assess the robustness and biofidelity of the head-neck complex.

II. METHODS

Experiments

In [1, 2] tensile tests on human cervical ligaments (both male and female) were carried out at three different strain rates. The tests included five types of cervical and six types of cranio-vertebral ligaments. The uniaxial response in tension of the ligaments was characterised in [1] by reaction force vs. ligament elongation. The geometry of samples and testing conditions were documented. The above mentioned dataset was clustered in this study by selecting only the experiments from male post mortem human subjects (PMHSs) in order to ensure a gender-specific stiffness response. The data showed variations in different samples owing to different spinal levels and ages. In order to account for these variations, a corridor was created based on the mean engineering stress-strain and an upper and lower bound defined by one standard deviation. Corridors including strain rate dependency were also generated.

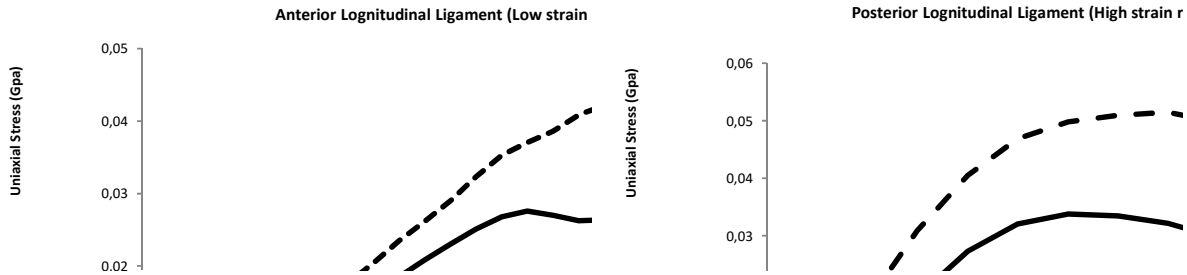

Fig 1. Male specific average stress strain data with upper and lower bound using standard deviations [1][2]

Computational modelling

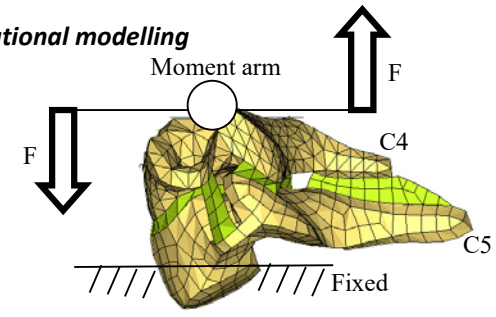

Fig 2.a Test Setup: Flexion of Cervical FSU [3]

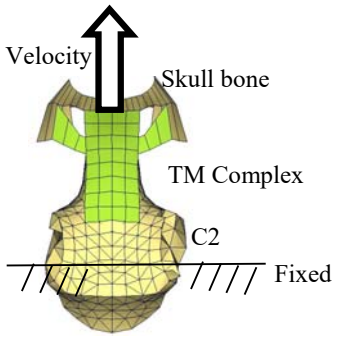

Fig 2.b Tensile test of FSU of the TM complex [1, 2]

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The base model was a THUMS v4.02 AM50 model in VPS [5]. The original mesh was kept. The model was reduced to two functional spine units (FSUs): (1) Cervical vertebrae (C4-C5) and (2) tectorial complex (TC) (Skull-C2). The new ligament materials based on the male-clustered data were included into these FSUs using a 2D membrane material model MAT151 in VPS [5] which allowed the application of a strain rate dependency and fibre orientation. A stiffness-based method using the plastic modulus was used for the hourglass control. Flexion of a FSU was chosen as validation basis as published by [3] where a moment arm up to 3.5 N-m was applied to the FSU while the flexion angles were recorded. The validation loadcase for the TM was a tension test defined by [1, 2] where a uniaxial tensile force was applied to the FSU till failure using a velocity to reach the desired strain rates.

III. **INITIAL FINDINGS**

The response in flexion of the cervical FSU (C4-C5) with the original THUMS (VPS) materials shows an unrealistic stiffness (approx. 2 deg. at 3.5 N-m) whereas the simulations with the clustered data generated in this study matches closely to the average curve of the experimental results (approx. 6 deg. at 3.5 N-m) (see Fig 3.a green line). A tensile test of the cranio-vertebral FSU [1, 2] consisting of the tectorial membrane (TM) complex (i.e. alar ligament, tectorial membrane and cruciform ligament) was simulated. The results showed that the force-displacement behaviour of the new material definition was well within the experimental corridor (see Fig 3.b green line).

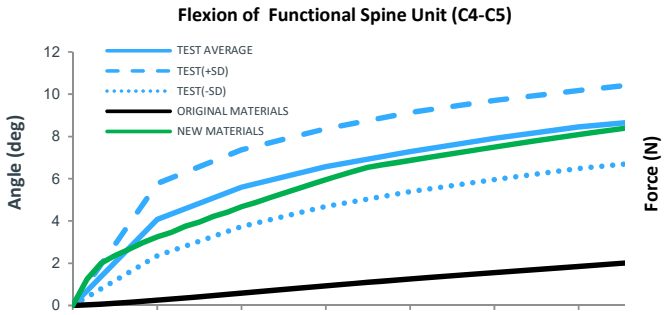

Fig 3.a Flexion test of the FSU [3]

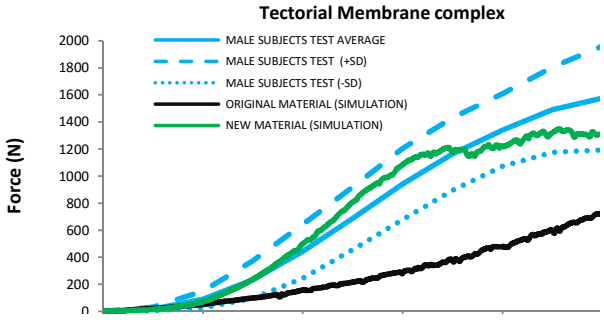

Fig 3.b Tensile test: tectorial membrane complex [1, 2]

IV. **DISCUSSION**

This study proposed clustering of the experimental data [1, 2] in order to create a gender-specific (male) linear stiffness corridor for cervical ligaments. The new material definitions showed good correlation when applied to male specific THUMS v4.02 AM50 (VPS). The simulation results prove to be more biofidelic for bending and tension component tests [1-3]. Further test in additional loading scenarios [4] are needed in order to validate the complete head-neck complex.

V. **REFERENCES**

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