CONCEPTION AND EVALUATION OF A MUSCULOSKELETAL FINITE ELEMENT MODEL OF THE THORACO LUMBAR SPINE

Marie Line Pissonnier (1), Antoine Perrier (1,2), Jerome Tonetti (3), Christian Garreau de Loubresse (4), Robert Carlier (5), Yohan Payan (1)

1. TIMC Laboratory, Biomeca Team, Grenoble Alpes University, France; 2. TwInsight, Grenoble, France; 3. Orthopaedic Surgery Department, Grenoble University Hospitals, France; 4. Orthopaedic Surgery Department, HEGP, APHP, Paris, France; 5. Medical Imaging Department, Raymond Poincare Hospital, APHP, Garches, France

Introduction

Most spinal pathologies can be responsible for damages to soft tissue and/or bone, resulting in a loss of mobility or, conversely, single- or multi-segment instability.
The purpose of modelling the human spine is to use computer simulation to help clinicians understand spinal pathophysiology and evaluate various treatment options. This work aims at developing a patient-specific musculoskeletal and Finite Element model of the thoraco-lumbar spine as a continuation of the lower limb modelling project initiated in the TIMC laboratory [1,2].

Methods

Radiological data (CT scan, MRI) from a healthy 36-year-old man were retrospectively collected after consent has been obtained for this study. The bones, muscles and ligaments of interest were segmented using Amira software (thermofisher.com). The thoraco-lumbar spine model has been developed using the 3D biomechanical simulation platform Artisynth (artisynth.org). It comprises 17 intervertebral discs modelled using 2-domains (annulus and nucleus) hexahedral finite elements, 53 bones (including 17 vertebrae) modelled as articulated rigid-bodies connected with 940 cables simulating the 11 ligament groups in their actual position and therefore defining joints with contact. The thoraco-lumbar fascia (TLF) is modelled with shell elements connected to bones or to muscles. A set of 15 muscles (represented by approximately 500 paths) is anatomically positioned. Via points along muscles courses were created to correlate with real muscle volume and torsion. Anatomical structures not visible on the images were modelled according to anatomical reference works [3].
To evaluate the model created from supine data, an original method using upright and dynamic radiological data was developed. It consists in comparing positional and angular parameters (intervertebral, regional, and global) measured on MR images with the same parameters simulated by the model.

Results

Figure 1 plots the whole model while table 1 shows the average length for 4 segmental ligament bundles (capsule, ligamenta flava - FL, interspinous and intertransverse ligaments, respectively ISL and ITL) at T12-L1 and L4-L5 levels and their Young moduli.
The data obtained should be compared with data from the literature [4].
Results concerning the simulations of dynamic and standing data are in progress.

Discussion

Only passive and proprioceptive structures are going to be analyzed in this study using pose controlling to reproduce upright mobilities. Further investigations are needed to assess active motion of the spine. Muscular coactivations will also be considered. For any clinical application, this reference biomechanical model built from data collected on a healthy volunteer will have to be transferable to the patient anatomy, in order to create his or her digital twin.

References

1. Perrier et al, Comput Methods Biomech Biomed Engin,18 Suppl 1:2024-5,2015.
2. Elyasi et al. J. Biomechanics, 132, 111062, 2022
3. Bogduk et al, Clinical and Radiological Anatomy of the Lumbar Spine, fifth Edition, 2012.
4. Remus et al, Front Bioeng Biotechnol, 27:11:1223007, 2023.
5. Goel et al, Spine, 20:2354-7, 1995
6. Pintar et al, J. Biomechanics, 25:11: 1351-6, 1992.
7. Chazal et al, J. Biomechanics, 18:3: 167-176, 1985.

Figure and Tables

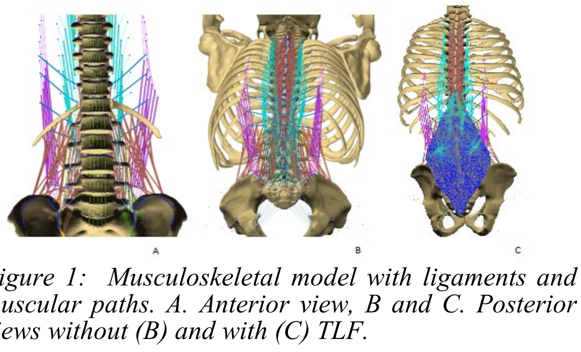

Figure 1: Musculoskeletal model with ligaments and muscular paths. A. Anterior view, B and C. Posterior views without (B) and with (C) TLF.

Structure	T12-L1 length (mm)	L4-L5 length (mm)	Young modulus (MPa)	Reference
capsule	6.225	6.25	7,5-33	[5] [6]
FL	27.25	20	13-19,5	[5] [7]
ISL	19.36	7.78	9,8-12	[5] [7]
ITL	33.5	23.67	12-58,7	[5]

Table 1: Ligament length at lumbar region.