DEVELOPMENT OF A COMBINED MSK AND FEA MODEL OF THE LOWER BACK

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Introduction

Lower back pain (LBP) is a debilitating condition affecting 85% of the population at least once in their life [1]. This condition is often considered to be idiopathic but related to spinal biomechanics. However, there is not a clear pathway between the deformation of spine structures and the development of pain. In many cases, LBP is also associated with an altered lower limb stability strategy [2], which could either be an attempt to protect the spine or a cause of pain. To investigate these hypotheses, a computational approach is being used combining a musculoskeletal (MSK) model of the full body with a structural finite element (FE) model of the lumbar spine. This combined modelling approach and its application to the study of the spine are presented here.

Materials and Methods

A full body MSK model composed of 566 muscle actuators for the lower limbs and lumbar spine was developed in *OpenSim*. The lower limbs are adapted from an existing MSK model [3]. The spine is composed of five articulated lumbar vertebrae linked to a three-segment upper body. Arms are also included for mass properties. The structural FE model is focused on the lumbar vertebrae. Cortical bone is modelled with shell elements and trabecular bone with beam elements. The bone structure is obtained from the bone adaptation algorithm developed by Phillips et al. and conclusively applied to the lower limb and pelvis [4]. An extensive range of everyday life activities is used in this algorithm to provide a complete spine load envelop for the structural adaptation. Activities include walking, sitting down, standing up, climbing stairs, lifting loads in different configurations of the spine and recovering balance after a perturbation. Intervertebral discs will also be modelled with a structural approach using a mix of continuous and structural elements. The two models are based on the same bone geometry segmented from MRI scans of a healthy volunteer.

The simulation pipeline consists in combining these two modelling techniques. Movement data of a specific task is first recorded with a passive optical motion capture system from *Vicon Nexus*. This data is used as input for inverse kinematics and inverse dynamics simulations with the MSK model to compute joint angles and moments. An optimisation problem where the overall muscle activation is minimized based on a quadratic muscle recruitment criterion is solved to compute the muscle forces required to produce the calculated joint moments. A joint reaction forces (JRF) analysis is performed to estimate forces and moments corresponding to the internal load carried by the joint structures. JRF and muscle forces are loading conditions for the simulations run with the FE model which finally give a physiological approximation of the mechanical environment of the spine structures. This approach will be used for a study on six healthy volunteers. For each participant the models are adapted from their MRI scans.

Results

Preliminary results were obtained with the MSK model and evaluated against in-vivo measurements [5, 6, 7] of JRF at three lumbar levels for three static positions, summarized in table 1.

Normalized to upright standing (%)	**L1-L2**		**L3-L4**		**L4-L5**	
	[5]	**Model**	**[6]**	**Model**	**[7]**	**Model**
Flexion	231	167	270	198	195	198
Extension	43	113	107	115	120	116
Lateral bending	136	98	161	106	125	107

Table1: Comparison between JRF at L1-L2, L3-L4 and L4-L5 levels.

Discussion

A dynamic assessment of the MSK model will be conducted using EMG recordings on the healthy volunteers when performing the different tasks. Future studies will include modifications of the MSK model by introducing muscle weakness to simulate altered biomechanics. Other studies will introduce structural deficiencies into the FE model that may produce a cascade response leading to LBP. Parametric modifications will also be made to the model to assess the effect of spine curvature on the mechanical environment of the spine structures.

Conclusion

The combination of MSK and structural FE models is believed to be a powerful tool for the investigation of LBP. The study presented here is expected to give insights on pain mechanisms and how they relate to the in-vivo mechanical environment of spinal structures under loadings experienced in various activities.

References

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