LUMBAR MUSCLE FORCES AND SPINAL LOADS DERIVED FROM EXTERNAL LOADING BY USING A MUSCLE CONSTITUTIVE MODEL

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Introduction

Spinal muscles transmit most of the kinematical forces to the spine tissues and therefore, careful modelling of muscle activity is critical for an adequate estimation of spinal loads. However, current lumbar spine numerical models overlook such muscle contribution or suggest simplifications that do not allow thorough studies of load transfers within the deforming spine. As such, this study proposes a novel active lumbar spine muscle model in order to estimate the muscle forces exerted during upper-body inclination and explore the influence of the muscles elements on the loads transferred to the vertebra and intervertebral discs.

Methods

A quasi-incompressible transversely isotropic hyperelastic model was adopted for the constitutive behaviour of the passive and active behavior of the lumbar muscles based on [1,4]. The constitutive model [7] accounted for the passive matrix (1) and active and passive muscle fibre strain energy terms (2), where $\bar{\lambda}_f$, the stretch ratio and ζ^{CE}, a strain-like active parameter based on the rest fascicle length.

$$U_{matrix}(J,\bar{I}_1) = \frac{K}{2} ln(J)^2 + \frac{G}{2}(\bar{I}_1 - 3) \quad (1)$$

$$U_{fib}(\bar{\lambda}_f, \zeta^{CE}) = T_0 \int_1^{\bar{\lambda}_f} f_{pas}(\lambda) d\lambda + T_0 \int_1^{\bar{\lambda}_f} f_{ac}(\lambda, \zeta^{CE}) d\lambda \quad (2)$$

Material constants for the passive resistance and muscle peak stress T_0 were based on [1,2,4], while for the active term, a parametric analysis was performed [7]. A sagitally symmetric muscle architecture of 46 fascicles was modelled for the Multifidus, the Longissimus thoracis pars lumborum and thoracis, the Iliocostalis thoracis pars lumborum and the Psoas Major based on [2]. The muscle network was coupled to a L3-S1 spine model based on [5] (Fig. 2a). A 10^o sagittal flexion was simulated and muscle forces, strains and intradiscal pressures (IDP) were estimated with (Model 1) or without (Model 2) muscle addition.

Results

Strain analysis (Fig. 1a) showed that, under flexion, almost 40% of all muscle fascicles underwent large deformations up to about 20% strains (MF). For all local muscles, i.e. MF, LTpL and IL, the strain was progressively higher at lower levels on the contrary of global fascicles, which were compressed. Fascicle force resultant (Fig. 1b) indicated that local muscles were highly resisting the flexion exerting up to 320N traction forces, while PS and LTpTh were less activated being under compression. The general tendency of global muscles to exert higher forces at the L4 level correlated with other studies [2,3]. The addition of muscles resulted to a significant increase of the reaction moment from 4.5 Nm (Model 2) to 45.2 Nm (Model 1) and also a 24% higher sagittal translation at L3 level. For Model 1, the predicted IDP between 0.73 and 0.9MPa were corroborated by numerical [6] and *in vivo* [8] studies. Fig. 2b shows the important effect of muscle presence on IDP predictions at all levels under flexion.

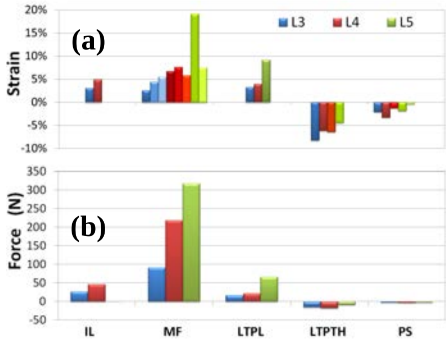

Fig. 1: Predictions of :(a) Strains per muscle fascicle and (b) Muscle forces per group, and per level (Flexion 10^o).

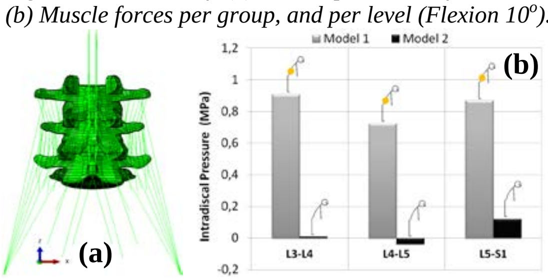

Fig. 2: (a) L3-S1 FE spine muscle model, (b) Muscle effect on IDP per level (Flexion 10^o).

Discussion

A novel active constitutive model for the lumbar muscles was proposed for the first time and was tested. The model captured the high resisting behaviour of local muscles under flexion and, depending on the deformation, could also capture the antagonism between PS and the local muscles [7]. The effect of muscle addition was significantly pointed out by the internal loads predictions and thus, this limitation of current studies was addressed by proposing a muscle constitutive formulation able to realistically estimate the spinal loads. Yet, further consideration of the full lumbar spine is an on-going work in order to better capture the muscle activity under different postures. The limited number of parameters (5) involved in the model among which, the morphology-based active parameter [7], could allow patient-specific calibrations through MRI and EMG measurements.

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References **[1]** Blemker et al., *J Biom,* 38:657-65, 2005. **[2]** Bogduk, *Elsevier,* 4th Edition, 2005. **[3]** Gagnon et al., *J Biom,* 17:1521-9, 2011. **[4]** Martins et al., *Comp Meth Appl Mech Eng,* 151:419-33, 1998. **[5]** Noailly et al., *J Biom,* 40:2414-25, 2007. **[6]** Rohlmann et al., *J Biom,* 42:1520-26, 2009a. **[7]** Toumanidou et al., *Proc VPH 2012,* 1-3, 2012. **[8]** Wilke et al., Spine, 24 (8), 1999.