Estimation of Intervertebral Efforts via an EMG-driven Multibody Model of the Sorensen Test

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EXTENDED ABSTRACT

1 Introduction

Spine is the central hinge of the human body. However, when correcting spinal surgery needs to be done, there is still a lack of objective information for its planning, such as intervertebral efforts. Indeed, intervertebral discs are the places where critical efforts occur in the spine. Spine geometry, kinematics and muscle forces are needed to compute these intervertebral efforts. If the first two are already tackled [1], assessing muscle forces is still challenging. For that purpose, both experimental and mathematical approaches can be used. Experimental methods consist in measuring directly or indirectly muscle forces through a well-targeted protocol. Electromyography (EMG) is commonly used although it is an indirect measurement. For these experimental methods, the number of participants is often limited. On the contrary, purely mathematical approaches allow to develop generic musculoskeletal models often based on the Hill muscle model and for which no experiment is performed. But parameters are numerous and difficult to estimate, all the more as these models deal with muscle redundancy.

The hybrid approach proposed in this research combines both experimental and mathematical approaches. It is based on an upfront experiment aiming at making the most of recorded EMG signals in order to develop musculoskeletal models. This approach was already presented previously for predefined static postures with encouraging results [2].

In this paper, the hybrid approach is used to assess trunk muscle efforts during the Sorensen test. Both static postures and dynamic motions are evaluated.

2 Materials and Methods

Nineteen healthy men (age: 22.7 $\pm$ 2.1 years; mass: 73.9 $\pm$ 8.7 kg; height: 1.81 $\pm$ 0.05 m) with no back pathology participated in the experiment. The latter was divided into three parts: (i) three maximal voluntary contraction (MVC) tests, (ii) five loaded isometric contractions and (iii) six dynamic flexion/extension tasks. All the three parts were carried out in the Sorensen test posture as depicted on the left in Figure 1. MVC tests were used for normalization. Loaded isometric contractions consisted in holding the position for 15 sec with a mass from 0 to 8 kg with 2-kg steps applied randomly. Finally, dynamic tasks were carried out for two cycle durations (4 and 8 sec) and for three masses (0, 2 and 4 kg).

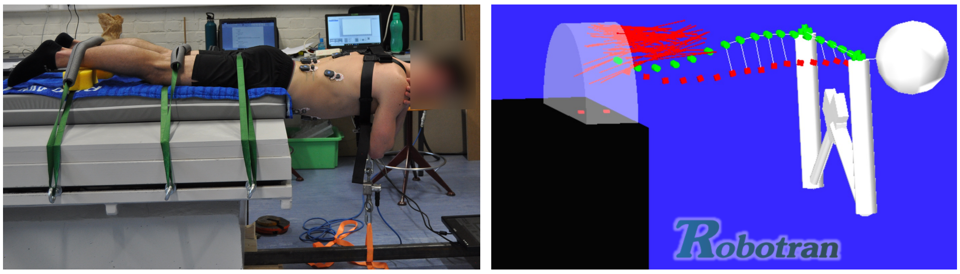

Figure 1: Sorensen test posture. Left: Experiment (UCLouvain 2020). Right: Multibody model in Robotran with muscles in red.

During the whole experiment, muscle activity of six bilateral trunk muscles was recorded using surface wireless EMG (BTS FREEEMG, 1000 Hz). Raw EMG signals were rectified, filtered using a 5th-order lowpass Butterworth filter with a cut-off frequency of 10 Hz, smoothed with a 150-ms window and normalized with respect to MVC contraction levels.

A musculoskeletal model of the trunk in the Sorensen test posture was developed using the multibody software Robotran [3] as illustrated on the right in Figure 1. It derived from a fully articulated thoracolumbar spine and rib cage model published previously [4]. It included fascicles of lumbar (LP) and dorsal (DP) paravertebral muscles and the quadratus lumborum (QL). It is worth mentioning that in the current hybrid approach, no optimization method was used for computing muscle forces. For isometric contractions, finding a unique mathematical solution was ensured with a deterministic muscle effort distribution. The idea was to use slopes from EMG linear regressions between activation levels (w.r.t. MVC) and lifted masses as indicators of the activation fraction for each muscle group (LP, DP and QL) for this precise effort situation. Then, inside each muscle group, the distribution between fascicles was based on their respective maximal isometric forces [4]. For dynamic tasks, muscle forces found in isometric contractions were used for calibration.

3 Results and Discussion

According to the previous process, muscle forces evaluation for isometric contractions was therefore equivalent to determine a unique 'global muscle force', the latter being distributed deterministically among all the fascicles. Normalized global muscle forces (global muscle forces divided by subject's mass) are depicted on the left in Figure 2 for all masses and all subjects. The normalized muscle forces were obviously linear w.r.t. lifted masses due the linearity of equations of motion. However, it was comforting to observe — not showed here — a relatively good linear dependence between activation levels and lifted masses as reported previously [5]. More interestingly, it can be seen that subjects recruiting more their QL (vertical blue scale) developed greater muscle forces compared to subjects using more their paravertebral muscles. A physiological explanation is the orientation of muscle fascicles, i.e. QL fascicles are more oblique to the spine while LP and DP fascicles are more aligned. It impacts directly the lever arm and consequently the muscle force required to meet the gravity-induced torque.

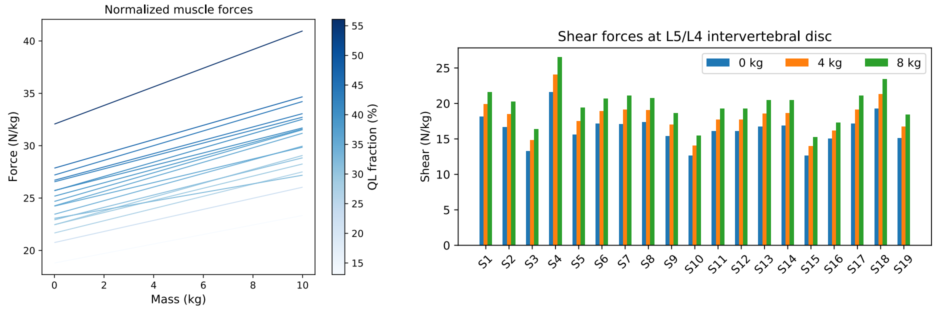

Figure 2: Loaded isometric contractions in the Sorensen test posture. Left: linear regressions between the normalized muscle forces and added masses. Right: normalized shear forces at L5/L4 intervertebral disc for three masses (0, 4 and 8 kg).

Intervertebral efforts — compressive, shear forces and bending moment — were also computed in order to evaluate the impact of individual strategies on them. Similarly to muscle forces, subjects using more their QL generated greater intervertebral efforts. This result was consistent with the greater global muscle force observed in those subjects and could also be explained by the orientation of QL fascicles. For illustration, shear forces for the L5/L4 intervertebral disc are showed on the right in Figure 2. Greater QL recruitment implied greater shear forces as in the subject S4. On the contrary, subjects 10 and 15 produced less shear forces as they used their paravertebral (LP and DP) muscles more. Shear forces had the greatest magnitude at the L5/L4 intervertebral disc compared to the other lumbar intervertebral discs. It must be reminded that shear forces in the Sorensen test posture are roughly aligned with gravity and are therefore particularly sollicitated. Compressive forces — not illustrated here — were also increased for higher QL recruitment and were greater for discs in the lower lumbar spine.

Experimental results and force computations for the dynamic tasks are currently under process and will be presented during the presentation.

4 Conclusion

Muscle forces associated to loaded isometric contractions in the Sorensen test posture were computed using an hybrid approach. This approach aimed at making the most of EMG signals from a well-designed experiment in order to develop the associated musculoskeletal model and the force computation in a deterministic way. Results highlighted the interest of considering individual motion strategies when evaluating muscle forces, particularly concerning the QL. Indeed, greater muscle forces and intervertebral efforts were obtained for subjects recruiting more their QL.

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