Quantifying intervertebral efforts during slow-dynamic trunk flexion/extension via a hybrid approach: a validation study

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Keywords*:* Spine; Intervertebral efforts; Hybrid approach

1. Introduction

In-vivo measurements are required to validate models and methods of computing muscle forces and joint efforts. These measurements are gathered in open-access databases to allow a larger accessibility. Among the latter, Orthoload (www.orthoload.com) gathers efforts of several joints measured in-vivo thanks to implanted prostheses.

In this study, the device of interest is the vertebral body replacement, which consists in replacing a spinal functional unit, i.e. a vertebra with its two adjacent intervertebral disc. Up to now, six patients were implanted (Dreischarf et al. 2015) to replace a vertebra. Once implanted, the patients were proposed to perform various daily tasks during which the in-vivo efforts inside the replaced vertebra were recorded in real-time.

Our objective was to confront our hybrid approach, i.e. an EMG-driven model, developed for static configurations to a dynamic case. Our approach relies on making the most of electromyography (EMG) as input of a musculoskeletal model of the trunk to compute muscle forces and resulting intervertebral efforts in the lumbar spine. These intervertebral efforts could be compared to the ones reported in the Orthoload database.

2. Methods

2.1 Experient

Two subjects participated voluntarily in this study. They were selected to match their anthropometric features with these from the subjects recovered in the Orthoload database – two for the selected motion. These features are summarised in Table 1 for all the subjects. Our subjects were with a good self-reported health, were recreationally active and never had back pathology.

Table 1*. Anthropometric features. Data for the Orthoload subjects are from Dreischarf et al. (2015) credit: Hinnekens*

	This study		Orthoload	
Subject	S1	S2	wp1	wp2
Height (m)	1.77	1.82	1.68	1.69
Mass (kg)	68	63	66	74
Age (years)	60	59	62	71
Sex	M	M	M	M
Fractured vertebra	/	/	L1	L1

The motion selected for the study was a trunk flexion/extension with a straight back when standing upright. The motion was performed three times: two as slow as possible and one at a self-selected speed.

EMG signals of back — lumbar (LP) and thoracic paravertebral (TP) muscles, quadratus lumborum (QL), latissimus dorsi — and abdominal — rectus abdominis, externus obliquus — muscles were recorded during the experiment. Maximal voluntary contractions were recorded prior to the exercises for EMG normalisation.

2.2 Model

A multibody model representing the studied motion was developed on the basis of a fully articulated thoracolumbar spine and rib cage model (Bruno et al. 2015). After analysis of the recorded EMG signals and several sensitivity analyses, only LP, TP and QL were involved into the model.

Muscle forces were quantified via an EMG-based deterministic distribution of a global equivalent force among muscle fascicles (Hinnekens et al. 2021). Muscle forces and resulting intervertebral efforts were computed for each time step by inverse dynamics, but considering the motion as a succession of quasi-equilibrium configurations for which velocities and accelerations were assumed to be equal to 0.

It was assumed that the whole trunk flexion/extension happened at the S1/L5 level. Intervertebral efforts were compared at the L2/L1 level which corresponds to the fractured level in the Orthoload subjects (Table 1).

In parallel with the validation of the database, linear regressions were performed between compressive forces computed by the model and flexion angles recorded during the experiment for comparison with the literature.

3. Results and discussion

Starting with the Orthoload comparison, compressive and shear forces computed by equivalent models of healthy subjects and those measured in Orthoload patients were in a similar range of magnitudes (Figure 1). Furthermore, they looked similar in their curve shapes, except for S1's shear forces. Additional comparisons with normalised forces were performed but are not presented here.

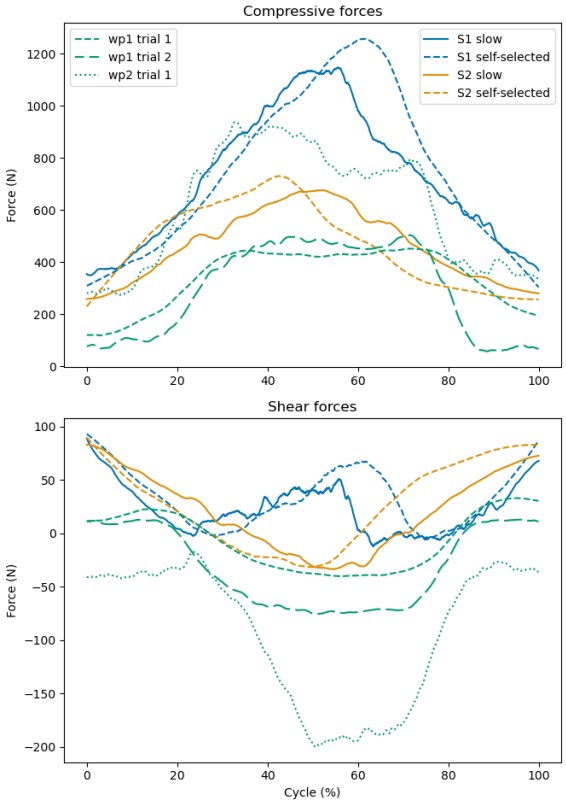


Figure 1. *Compressive and shear forces for all subjects and all trials – Comparison between this study (S1, S2) and Orthoload (wp1, wp2). credit: Hinnekens*

For compressive forces, the similarity was relatively obvious with a bell-shaped curve, in particular for healthy subjects. There was a plateau for each curve of Orthoload subjects, as observed for the flexion angles (not showed). The plateau was actually explained by the motion performed by the Orthoload subjects, i.e. they did not keep their back exactly straight. Indeed, the flexion could be split in two, with a sagittal rotation of the pelvis first followed by a slight rotation at the level of another spine segment. Globally the back was straight but the real strategy produced a plateau on compressive forces. Dreischarf et al. (2015) corroborated this explanation in their study.

Shear forces in Orthoload subjects were opposite to these obtained with the model and the hybrid approach. These differences might be explained by the implant itself. Indeed, forces measured by the implant were for a vertebral functional unit while the forces computed with the hybrid approach were associated with one disc level. Also, the Orthoload subjects could have developed an adaptive strategy following their injury, operation and rehabilitation which could result in a different distribution of intervertebral efforts.

Finally, there was a linear correlation between compressive forces and the flexion angle (not showed). In particular, compressive forces at the L5/L4 level fitted well the linear regression proposed by Takahashi et al. (2006). It meant that even with a relatively simple deterministic distribution of a global equivalent force into all the muscle fascicles, the method was accurate enough to compute representative compressive forces. It would suggest that considering the back muscles as pure force transmitters, i.e. no muscle-length or muscle-velocity relationships, could be sufficient for dynamic configurations.

4. Conclusions

This study highlighted the potential of using a hybrid approach developed for static configurations to dynamic cases. Intervertebral efforts, especially compressive forces, were similar with in-vivo measurements from an open-access database. Furthermore, compressive forces computed with our method matched the linear regressions reported in the literature. Future work will focus on considering the muscle dynamics for a more detailed comparison.

Conflict of Interest Statement

The authors state that they do not have any conflicts of interest.

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Received date: leave blank
Accepted date: leave blank
Published date: leave blank
Volume: leave blank
Publication year: leave blank