# Total and local experimental validation of a lumbar spine numerical model to enhance the orthopaedic management of spinal metastases

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## Abstract

This work shows a full biomechanical validation of a multibody lumbar model with respect to an experimental phantom, fruitful for giving major insights on different surgical vertebral metastasis treatments.

## Introduction

The surgical removal of lumbar vertebral body metastasis requires the stabilization of the spine, which is realized, at present, by an extremely invasive procedure consisting in the application of 8 pedicles screws and the fixation of the pathological vertebra with its two superior and inferior adjacent ones. This surgical layout permits a proper biomechanical stabilization at the expenses of spinal mobility, entailing relevant side effects (*i.e.*, overload and rapid degeneration of healthy structural elements of the column, limited range of motions). In this framework, new forms of surgical procedures are being suggested, but their efficacy, in terms of stabilization and load distribution, needs to be proved and verified. Multibody modelling could support the adoption of new solutions predicting their ensuing biomechanical outcomes. Unfortunately, the existing multi-segmental multibody models are mainly validated by recurring to data obtained from single functional units' studies, which do not fully reflect the comprehensive behaviour of multi-vertebral structure.[1] Hence, this study is intended to provide both a total and local characterization of a validated rachis phantom to permit an exhaustive validation of a complete lumbar *in silico* model useful to provide robust insights on the biomechanics of novel different surgical layouts designed for spine metastases.

## Materials and Methods

A joint approach, embracing experimental tests and multibody modelling, was then adopted. The experimental protocol consisted in 4 different motion-controlled loads (flexion, extension, compression, and torsion), designed for a linear-torsion test machine (Instron E3000) and applied to a validated Sawbones lumbar spinal phantom (T12 to S1, SKU3430) in its elastic field. The range of motions were limited in order to perform conservative tests and not to overcome the Neutral Zone of the single FSUs.[2] Relative displacements between vertebrae, postprocessed in GOM*correlate* environment, were also included by the means of planar motion tracking: markers were positioned on the vertebral bodies surfaces and on their spinous processes.

Furthermore, a multibody model was implemented from the Sawbones CAD geometry in MSC Adams. In accordance with the phantom, the passive elements of the spine were included in the model: ligaments were modelled as pre-strained non-linear tension-only springs, while IVDs were represented as bushing elements oriented coherently with the adjacent vertebrae's endplates.[3,4] To properly compare the results, the experimental loading protocol was replicated in the numerical environment.

## Results

Starting from data obtained experimentally, the global whole lumbar segment stiffnesses were computed (Table 1). In the investigated ROM, an almost linear behaviour of the dummy was enregistered. Accordingly, the stiffnesses were obtained as the slopes of the angle (T12-L5) - force linear approximation curves ($R^2 > 0.93$).

Concerning the analysis of vertebrae's relative kinematics during the anterior-posterior bending, the angles between the horizontal axis and the lines joining spinous process centers with the vertebral body centre of mas, were measured ($\Delta\phi$). The multibody model showed a good consistency

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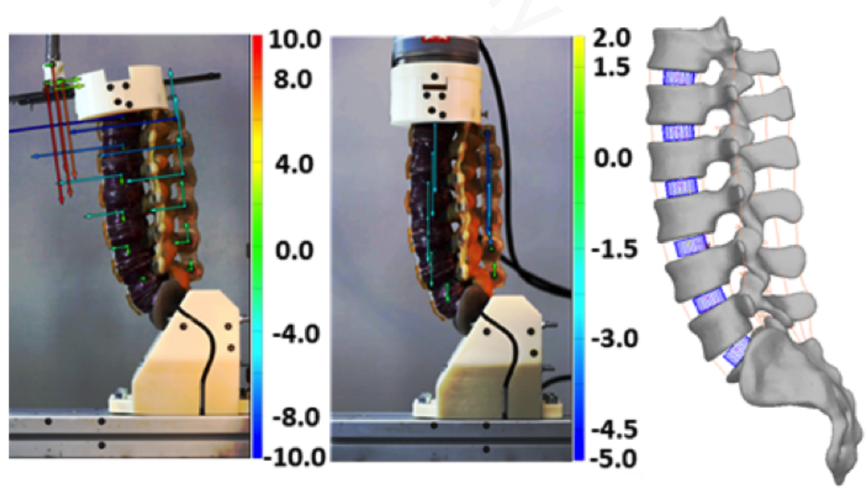


**Figure 1. Left and center: experimental setup and kinematic study for the flexion and compression loadings. Right: the lumbar spine multibody model.**

with the experimental results (max discrepancy of 2.5 standard deviation).

Figure 2 reports the case of the anterior bending: although the almost negligible variability of experimental results, the *in silico* model not only showed the same cranio-caudally decreasing pattern but also close values correspondence.

In the same way, numerical displacements during compression deviate of the 8% at the maximum amplitude of the experimental motion. Torque was validated only in terms of stiffness since the displacements were out of the sagittal plane.

## Discussion and Conclusions

The achievement of a comprehensive validation of a numerical model of the whole lumbar spine will reveal a precious tool to reproduce clinical scenario and thus investigate new forms of surgical outcomes. The proposed twofold validation approach (accordance with experimental kinetics and kinematics) will consent a robust and reliable way not only to assess the stability of the vertebrae-implant system but also to evaluate the forces at play and the remaining mobility of the column relative to the physiological condition. Those aspects are crucial for the durability of the fixation, the quality of the patients' postoperative life and the risk of implant failure.

Finally, this numerical contribution can support the pre-clinical studies of new orthopaedic fixation devices, pursuing a 3R approach for a more effective surgical management of spinal metastasis.

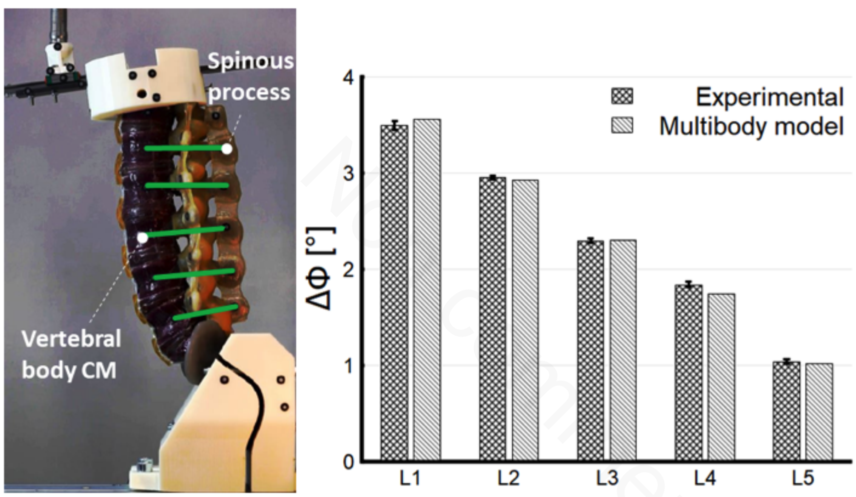


**Figure 2. Left: Construction of the vertebral orientation paramenter $\Delta\phi$. Right: Comparison of the experimental and numerical $\Delta\phi$ at the maximum displacement imposed during anterior bending.**

**Table 1. Results and comparison between experimental ('Exp') and numerical ('Num') lumbar spines' stiffness concerning the global stiffnesses for different motion-loadings. Experimental data reports the mean and standard deviation of 6 replications.**

| Motion | Exp | Num |
|---|---|---|
| Flexion [Nm/deg] | 1.49 ± 0.06 | 1.75 |
| Extension [Nm/deg] | 3.45 ± 0.07 | 3.03 |
| Compression [N/mm] | 94.4 ± 0.64 | 87.8 |
| Torque [Nm/deg] | 2.7 ± 0.01 | 2.8 |



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