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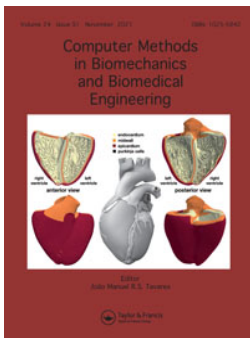
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Ex vivo experiments on vertebral segments with simulated lytic metastases

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1. Introduction

Vertebral fractures of the spine are common for patients with bone metastases. This can lead to neurological deficits as well as alter the quality of life of these patients. These skeletal related events induce important health care cost due to treatments such as radiotherapy or surgery (Algra et al. 1992).

To assess the fracture risk, the Spinal Instability Neoplastic Score (SINS score), ranging from 0 to 18, is based on parameters including the patient's pain, the type of metastasis, the size or the location of the metastasis. However, this score lacks of sensitivity to estimate the fracture risk for values between 7 and 12 (Fox et al. 2017).

To improve prediction, biomechanical models have been developed (e.g. Groenen et al. 2018), but experimental data are still needed for validation purposes.

The aim of this study was to provide biomechanical data in the case of defect affecting partly the vertebral body and one pedicle.

2. Methods

2.1. Specimens

Six lumbar vertebral segments (L2-L4) (3 females, 3 males, 79.8 ± 10.3 y.o) were provided by the Département Universitaire d'Anatomie Rockefeller (Lyon, France) through the French program on voluntary corpse donation to science. Bone mineral density was measured using Dual X-ray Absorptiometry (mean value of 0.955 ± 0.21 g/cm²). The defects mimicking osteolytic metastatic lesions were performed by a spine surgeon on the L3 vertebra in the vertebral body (30% the vertebral body volume) and one pedicle (Figure 1a), using a driller and diamond disk (Dremel 4000). The vertebral segments were imaged by quantitative computed tomography

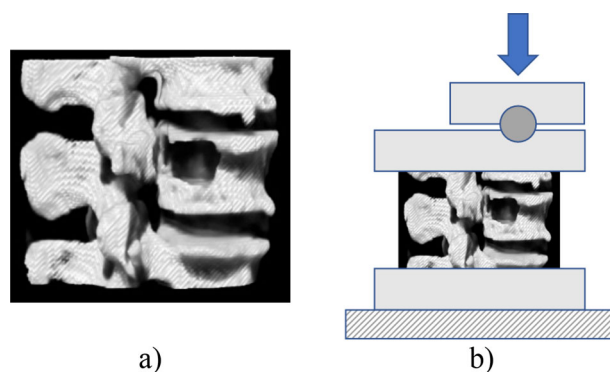


Figure 1. (a) 3D reconstruction of the vertebral segment with the defect in the posterior part of the L3 vertebral body including the removal of one pedicle, b) diagram of the compression test.

Table 1. Biomechanical data for lumbar vertebral segments (L2-L4) with defect in L3 (part of the vertebral body and left pedicle removed), loaded in anterior compression.

Nb	Age (Female/Male)	Failure load (N)	Stiffness (N/mm)	ϵ von Mises at failure load (%)
1	96 (F)	1711	390	6
2	75 (M)	2255	398	1.8
3	67 (M)	4895	1688	3
4	85 (F)	2826	730	4.7
5	78 (M)	2053	459	2.3
6	80 (M)	—	1536	—

on a GE Medical system (Hospital E. Herriot, Lyon) using a Model 3 CT Calibration Phantom (Mindways Software, Inc. Austin, USA), before and after the defect creation.

2.2. Mechanical experiments

The L2 and L4 vertebrae were embedded in polymethyl methacrylate (Figure 1b). A speckle was projected on the L3 vertebra in order to compute the bone displacement and von Mises strains using stereo-correlation (VIC-3D 2010, Correlated Solutions Inc.).

The vertebral segments were loaded, using a servo-hydraulic testing machine (Instron 8802), under a quasi-static (1mm/min) anterior compression (with a ball joint) until failure (Sapin-de Brosses et al. 2012). The failure load and the stiffness were computed from these experiments. The position of each vertebral segment on the testing device was captured by a laser scanner (Nikon Metris MCA II model 5128) to be able to reproduce it in a further biomechanical model.

3. Results and discussion

The data from the biomechanical experiments are given Table 1. The average failure load was 2748N

(standard deviation (SD): 1267N), while the average stiffness was 867 N/mm (SD: 592 N/mm). The maximum bone displacement of the L3 vertebra was between 0.4 and 1.9 mm. The mean von Mises strain computed from stereo-correlation was 3.6% (SD: 2%).

Due to the specific configuration of the vertebral segments (defect in the vertebral body and resection of one pedicle), failure was not characterized by a sharp drop of the load. The applied loading induced a progressive compaction of the vertebral segment. For one segment (Number 6), the failure load was not reached at the end of the experiment (global displacement of 6.5 mm). The stiffness was computed from the displacement of the upper platen. Thus, the displacements of the intervertebral discs were included. This stiffness gives a global response of the vertebral segments.

As expected, the maximum bone displacements were located in the cortical area close to the defect created by the surgeons.

The von Mises strain at the failure load could be compared to the results of further biomechanical models. In one experimental case, this value was not computed because of fluid leakages on the surface analysed by stereo-correlation. This problem is a limit of this measurement technique (Palanca et al. 2018) and was probably more important in the current study due to the defect created in the cortical shell of the vertebral body. Some additional limits should be noted. The number of cases are low, but could be used for subject-specific modelling. The lytic defects created as holes are less representative than real metastases. However, they represent a worst case scenario. The originality of the current study is the deleterious location of the defect.

4. Conclusions

This study provides data for further validation of biomechanical models of vertebral segments with defects

representing lytic lesions affecting both the posterior part of the vertebral body and one pedicle.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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KEYWORDS Lumbar vertebrae; failure; defect; strength; strain

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