A Physical 3D Printed Model of the Lumbar Spine as a Teaching Tool: Experimental Testing of the Intervertebral Disc under Axial Compression

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Summary

This study focused on the development of a simple physical 3D printed lumbar spine model to use as a teaching tool, consisting of functional spinal units (FSUs) with realistic responses under compression. The mechanical responses of the L4/5 intervertebral disc (IVD) were compared with existing *in vitro* and *in silico* data. The results indicated that the IVD made from thermoplastic polyurethane (TPU) with 72 % infill and silicone Shore 30 (S30) closely mimics the compression behaviour of a human IVD between L4 and L5 up to 1000 N.

Introduction

Anatomical knowledge is essential for developing medical devices. Future developers, e.g. students in engineering, only gain limited insight into this topic in their higher education but need them to develop medical devices. [2] Cadaver labs during their studies would be useful but are not often feasible [1,2,]. Physical models, such as 3D printed models, are valuable tools for understanding complex anatomical structures, including spatial knowledge, e.g. in the lumbar spine [3]. A key advantage of physical 3D printed models is the ability to facilitate visual and haptic understanding, an aspect that 2D or digital representations cannot achieve [3]. Thereby, 3D printed models can be used to provide hands-on experiences, such as certain steps of lumbar fusion and achieve high levels of educational efficacy [2]. This study aims to develop a 3D printed model of the lumbar spine to teach spatial knowledge in anatomy classes for engineering students. Therefore, the L4/5 FSU was experimentally tested to evaluate its mechanical behaviour under axial compression.

Methods

The 3D printed model of the L4/5 FSU comprised two vertebral bodies (VBs) and the IVD, based on the numerical model of Remus *et al.* [7]. The anatomical structure was simplified, leaving the VBs with the IVD. The VBs and the nucleus pulposus (NP) were made in a 3D printer (Prusa MK3S+ MMU3); the VBs were made of PLA, and two NPs were made of TPU with 60 % and 72 % infill. The annulus fibrosis was made of silicon with S30. The samples were loaded in a materials testing machine (Zwick Z010) with an axial compression force continuously increasing (20 mm/s) up to 1000 N. The model responses were compared with *in vitro* studies [4,5,6] and an *in silico* model [7].

Results and Discussion

Experimental and *in silico* results with *in vitro* data [4,5,6] are shown in Figure 1. The IVD made of TPU 72 %/S30 exhibits compression behaviour comparable to the *in vitro* data. The IVD made of TPU 60 %/S30 demonstrates comparable compression behaviour up to 600 N. Beyond, a greater compression is observed compared to the IVD out of TPU 72 %/S30, the *in vitro* studies and the *in silico* model.

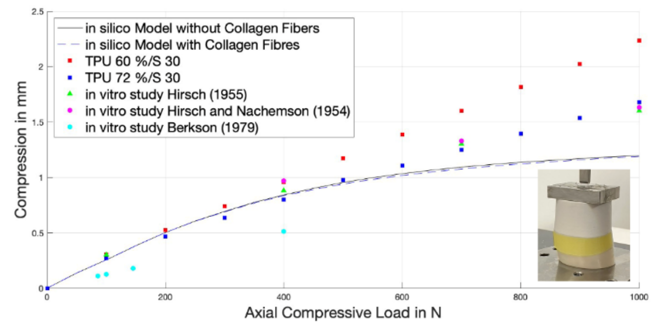

Figure 1: Compression behaviour of the FSU L4/5 of the *in silico* model, the tested physical 3D printed model, and the *in vitro* studies [4,5,6] under axial compressive load.

The highly simplified FSU mimics a valid compression behaviour of an IVD. While this test provides a basic assessment, it does not describe the entire physiological behaviour of the lumbar spine. Nevertheless, it represents an initial step toward developing a physical 3D printed model to teach the anatomy of the lumbar spine to engineering students. Further works involve testing the range of motion and increasing the complexity of the model with ligaments and facet joints to visualise the whole anatomy of the lumbar spine.

Conclusions

Physical 3D printed models can effectively replicate the mechanical behaviour of the human body and show the biomechanical effects of the IVD under axial compression. Using a physical model as a teaching tool can be a suitable choice for anatomical education for engineering students. Further optimisation could enhance the complexity of the model, enabling its broader application in medical education and medical device development.

References

[1] Carmichael S, Robb R (2008), *Anat. Sci. Educ.*: **1**, 90-91.
[2] McConnell D et al. (2017), *J. Geol. Educ.*: **65**, 604–625.
[3] Salazar D et al. (2022), *Med. Sci. Educ.*: **32**, 1209–1218.
[4] Hirsch C and Nachemson A (1954), *Acta Orthop.*: **23**, 254-283.
[5] Hirsch C (1955), *JBJS*: **37**, 1188-1196.
[6] Berkson M et al. (1979), *J. Biomech. Eng.*, **101**, 53-57.
[7] Remus R et al. (2021), *PLoS ONE* : **16**,e0250456.