

How Physiological Loading Protocols Affect Kinematics for In-vitro Testing of the Spine

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Disclosures: The authors have no disclosures to submit.

INTRODUCTION: Back pain and spinal disorders are a global issue and a root of both social and economic burden. A key aspect in characterizing spine function lies in determining the forces which are transferred through the spine. However, this is difficult to achieve through in vivo measurements. This challenge may be addressed through the current project, which is developing and testing a novel image-driven approach that will allow the loads in an individual's spine to be estimated by incorporating information acquired from multimodal imaging (MRI and biplane X-rays) in a subject-specific finite element model. This initial phase of data collection, which will provide the foundation for the in-silico model, entails collating in vitro biomechanics of porcine, bovine and human lumbar specimens, on a custom 6-axis test system. This abstract includes the preliminary data for the first porcine specimens and seeks to compare how three different loading protocols affect the test kinematics and evaluate the physiological relevance of each protocol.

METHODS: A porcine lumbar spine was acquired fresh, within one hour of culling. Functional spinal units (FSUs) (n = 3, L1-2, L2-3, and L3-4) were dissected using 3D printed cutting guides, produced from segmented CT data. The FSUs were individually potted in testing fixtures using dental acrylic, and k-wires to aid positioning. The specimens were then tested using a bespoke 6-axis test system. An axial compressive preload of 360 N was applied for 20 minutes. The specimens were then run through three stages of testing: stiffness matrix (SM); pure moment (PM); and OrthoLoad profiles (OL) from in vivo data measured using instrumented vertebral body replacements [2]. SM testing used position-based control to test each of the 6 axes (Tx, Ty, Tz, Rx, Ry, Rz) individually, with all other axes held static. The range of motion (ROM) used for each axis was based on previous tests [1]. PM testing used the same ROM applied in position control as the SM tests, however the remaining axes were maintained in load control with a desired load of zero N or Nm, except axial compression, which was maintained at 360 N. Finally, OL testing applied the 6-axis load profiles of nine different activities taken from the OrthoLoad database [2]. These were completed in 6-axis load control, at a speed factor of 50%. Based on varied peak outputs for the three loading protocols, the same rotational moment was chosen across all protocols, and the rotation and translation magnitudes at this moment were used to compare the kinematics. The rotational moments were 1 Nm for both flexion and lateral bending, and 0.5 Nm for axial rotation.

RESULTS: As expected, all translation values for SM testing remained at zero. The rotation at the set moment was comparable between SM and PM tests but was substantially lower in OL tests. There was a minimal change in the center of rotation (CoR) between both SM and PM, with the exception of flexion during the pure moment tests, where there was a consistent increase in the Tz axis of 0.16 ± 0.03 mm. Conversely, the OL protocol resulted in a decrease in the Tz axis of 0.21 ± 0.13 mm. During lateral bending and axial rotation, OL tests indicated an increase in Tz, of 0.21 ± 0.05 mm and 0.25 ± 0.06 mm, respectively, which was not observed in the SM or PM tests.

DISCUSSION: The primary limitation with this pilot data is the current sample size, however apparent trends are forming already. Stiffness matrix testing is easy to control and provides functional, efficient data for modelling purposes, however it does not recreate physiological movement. As shown from the data, no translation occurs during rotational movements. Pure moment testing is widely utilized on the basis that it is more physiologically relevant than SM testing, however it is still limited. As shown by the data, the superior vertebra rises upwards during flexion, which is not physiologically accurate. OrthoLoad profile 6-axis testing, albeit derived from non-healthy volunteers, is the closest replication of physiological movement, as shown by the axial compression during flexion. This provides a basis for continuing with 6-axis testing, in order to achieve the best physiological representation of in vivo kinematics.

SIGNIFICANCE/CLINICAL RELEVANCE: This study demonstrates that more simplified loading protocols do not represent physiological kinematics, however, the 6-axis system of the present study is capable of testing more relevant loading profiles, and this system will provide the basis for a larger research objective to develop image-driven subject-specific spine models. This research pipeline will provide a new tool for determining loads in the spine, measuring and modelling spinal kinematics, and quantifying the properties of spinal tissues.

REFERENCES: [1] Holsgrove et al, 2014. The Spine Journal, 14(7): p1308-1317. [2] Bergmann G. and Damm P. (ed.), Julius Wolff Institute, Berlin Institute of Health at Charité Universitätsmedizin Berlin (2008) "OrthoLoad".

ACKNOWLEDGEMENTS: The authors would like to thank the UK Engineering and Physical Sciences Research Council (EPSRC) for funding this project: EP/V036602/1 (Meakin, Holsgrove & Javadi) and EP/V032275/1 (Holt & Williams).

IMAGES AND TABLES: Image 1: A diagram of the directions of both translations (T) and rotations (R) of each axis, against a function spinal unit [1].

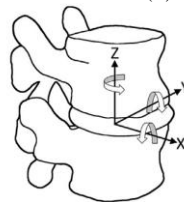


Table 1: A comparison of resultant rotations and translations, based on a fixed magnitude of flexion, lateral bending or axial rotation, across three different test types, within single porcine lumbar specimens.

Test Type	Flexion				Lateral Bending				Axial Rotation			
	Ry [deg]	Tx [mm]	Ty [mm]	Tz [mm]	Rx [deg]	Tx [mm]	Ty [mm]	Tz [mm]	Rz [deg]	Tx [mm]	Ty [mm]	Tz [mm]
Stiffness Matrix	1.17 ± 0.69	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.96 ± 0.26	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.25 ± 0.08	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Pure Moment	1.10 ± 0.49	0.05 ± 0.13	-0.04 ± 0.03	0.16 ± 0.03	0.90 ± 0.26	0.11 ± 0.06	0.15 ± 0.03	0.01 ± 0.06	0.23 ± 0.05	0.12 ± 0.08	-0.03 ± 0.04	0.01 ± 0.06
OrthoLoad	0.41 ± 0.18	-0.68 ± 0.26	-0.26 ± 0.03	-0.21 ± 0.13	0.54 ± 0.23	-0.1 ± 0.09	-0.05 ± 0.05	0.21 ± 0.05	0.05 ± 0.03	0.07 ± 0.13	0.26 ± 0.06	0.25 ± 0.06