Development of an integrated spine biomechanics framework combining in-vivo, in-silico and in-vitro methods

Ebisch I[a], Farris DJ[b], Lazaro-Pacheco D[a], Holsgrove TP[a]

[a] *Department of Engineering, Faculty of Environment, Science and Economy, University of Exeter, Exeter, UK.*

[b] *Public Health & Sport Sciences, Faculty of Health and Life Sciences, University of Exeter, Exeter, UK.*

Lifestyle heavily influences intervertebral disc (IVD) loads, but measuring in-vivo loads is not possible without invasive procedures, and the ability to apply these loads in-vitro is limited. While valuable in-vivo load data is available from instrumented vertebral body replacements (IVBR) via the Orthoload-database [2], these data are acquired from participants with a spinal fusion, which may not result in the same loading as a healthy population, or a back pain population that has not had spine surgery. Therefore, this study aimed to develop an integrated framework for the non-invasive estimation of in-vivo IVD loading, and the application of these loads in the in-vitro setting (Figure 1).

A full-body Opensim model was developed by adapting two existing models [3,4]. Kinetic data from five healthy participants performing activities of daily living were acquired and used as inputs for simulations using static optimisation. After validating simulation results using in-vivo data [2,5,6], the estimated six-axis loads were applied to bovine tail specimens.

Estimated spinal loads from the in-silico model followed the same trends as Orthoload-data [2] but resulted in higher magnitude loads. The modelled magnitude in axial compression was comparable to that derived from in-vivo intradiscal pressure measurements of healthy participants [5,6]. This highlights the potential differences between healthy and IVBR populations. Estimated L1/L2 loads were successfully applied to bovine tail specimens, with loads scaled for the smaller size of the IVDs, resulting in similar kinematics in the in-vitro tests as the in-silico models (Figure 2).

A framework has been successfully developed, and key components validated that allows the estimation and application of physiological load profiles to IVDs. This can be used to estimate the complex loads of daily activities in different populations, which will deepen our knowledge of spine biomechanics, mechanobiological processes involved in IVD degeneration, and improve the pre-clinical test methods.

References

[1] Alzahrani, H., Shirley, D., Cheng, S. W. M., Mackey, M., & Stamatakis, E. (2019). Journal of Sport and Health Science, 8(4), 386–393.

[2] Bergmann, 2008. "OrthoLoad". Retrieved 01/04/2021 from http://www.OrthoLoad.com

[3] Beaucage-Gauvreau, E., Robertson, W. S. P., Brandon, S. C. E., Fraser, R., Freeman, B. J. C., Graham, R. B., Thewlis, D., & Jones, C. F. (2019). Computer Methods in Biomechanics and Biomedical Engineering, 22(5), 451–464.

[4] Senteler, M., Weisse, B., Rothenfluh, D. A., & Snedeker, J. G. (2016). Computer Methods in Biomechanics and Biomedical Engineering, 19(5), 538–548.

[5] Takahashi, I., Kikuchi, S., Sato, K., & Sato, N. (2006). Spine, 31(1), 18–23.

[6] Wilke, H.-J., Neef, P., Hinz, B., Seidel, H., & Claes, L. (2001). Clinical Biomechanics, 16(S1), S111-S126.

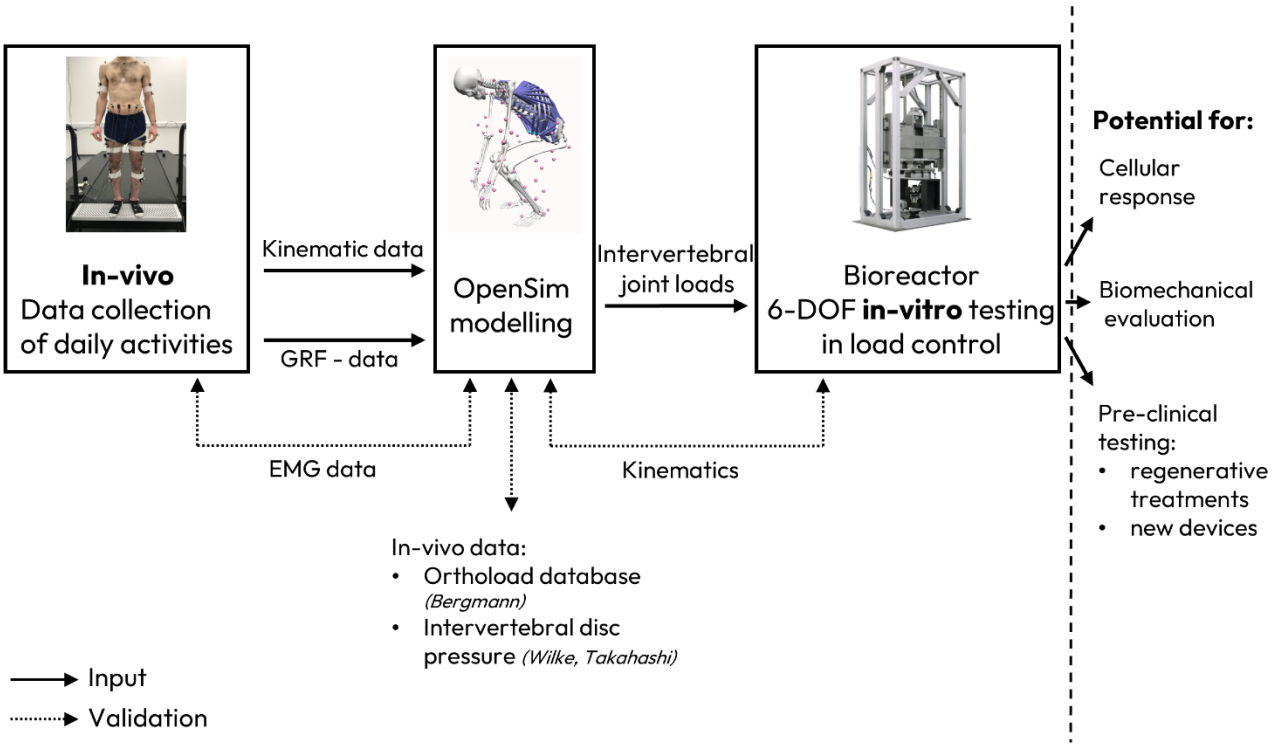

Figure 1 Schematic of framework: From in-vivo data collection of participants performing activities of daily living to six-axis in-vitro testing of spinal specimens.

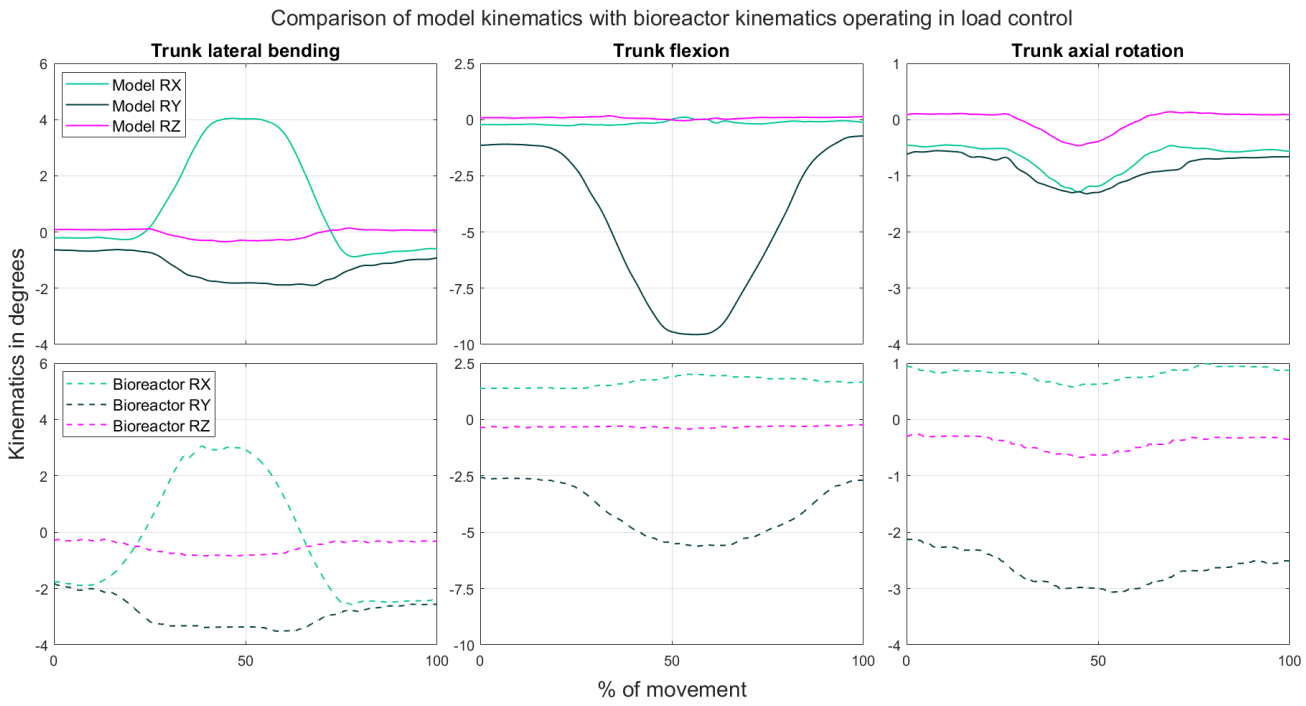

Figure 2 Comparison of model kinematics (rotations around all three axes) at L1/L2 level with bioreactor kinematics for a trunk lateral bending (RX), trunk flexion (RY), and trunk axial rotation (RZ).