Design and validation of 3D printed analogous lumbar model for use in a robotic benchtop spine model

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Many cadaveric studies and Finite Element (FE) models are used to explore the biomechanics of the lumbar spine and spinal stability in the past and yet the pathomechanisms of many low back related diseases are not fully understood. Cadaveric studies often involve assumptions pertaining to patient's previous medical history [1]. FE studies on the other hand are not modeled to the extent of human complexity to optimize the solution time. These shortcomings may be addressed by having a valid benchtop spinal testing platform with integrated soft tissues and sensors. Thus, this study aims to develop and validate a fully 3D printed lumbar spine benchtop model for use in an analogous robotic spine model. Such a model would complement existing methods of in-vivo and in-silico studies related to spinal stability and low back pain.

The vertebral bodies, intervertebral discs (IVD) and ligaments are manufactured using stereolithography 3D printing. Their geometry is based on 3D MRI patient data, while the ligament geometry is adjusted to incorporate mounting points on the vertebral bodies. Elastomers of shore hardness 50A and 80A are used to manufacture IVDs and ligaments. Three disc designs as well as three combinations of disc and ligament material choices are tested and their rotational stiffness and intradiscal pressure during flexion-extension motion is recorded. Five cycles of ±10 degree rotational displacement at 0.5 deg/sec is applied and the average resisting moment is recorded for rotational stiffness. Force resistive sensors embedded inside the discs measure the intradiscal pressure (IDP) during the experiment.

The setup is compared to similar benchtop [2] and FE models [3] reported in literature, and it is found that the 3D printed models extension zone (EZ) stiffness is 0.55±0.19 Nm/deg and is approximately four times less stiff than the human disc. When appropriate scaling factors are applied, the values fall inside ±1 standard deviation corridors of human disc in rotational stiffness across ±10 degree range. Model IDP is recorded to increase at a rate of 0.07MPa/deg across ±10 degree range and also fall inside ±1 standard deviation corridors at two times scaling when compared to the FE model reported in [3].

This fully 3D printed lumbar spine model is validated, with relative scaling, for rotational stiffness and IDP during flexion-extension of ±10 degree range and such a platform can be used to simulate different patient specific loading scenarios to test spinal stability.

References

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