CAN THE MULTI-DIRECTIONAL BENDING PROPERTIES OF THE LUMBAR INTERVERTEBRAL DISC BE PREDICTED FROM THE COMPONENTS OF THE PRINCIPAL ANATOMICAL AXES?

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INTRODUCTION:
The biomechanical properties of the human lumbar intervertebral disc about the three principal anatomic motion axes of axial rotation, lateral bending, and flexion/extension have been well studied. However, it is unknown if these values can be extrapolated to physiologic motion axes (i.e. motions that are combinations of two or three of the principal motions). Such information would be crucial for a more detailed understanding of the human spine and the critical evaluation of artificial disc replacement systems now being widely developed.

We hypothesized that the biomechanical properties about combined axes are a linear combination of the component principal axes. To test this hypothesis the mechanical properties of spinal segments were measured about the three principal axes and about ten combined axes. After determining the influence of the direction of loading, we compared the experimental values about the combined axes to those values predicted from the values about the principal anatomic axes.

METHODS:
Seven human lumbar spinal specimens (L2/3 and L4/5) were obtained from cadavers (mean age 63.3 ± 3.0 years). Anterior column units, prepared by removing all of the posterior elements from functional spinal units were potted and mounted in a pure-moment, unconstrained testing apparatus designed to interface with a biaxial servohydraulic load frame. The apparatus was indexed in 45º increments about two perpendicular axes such that moments (± 8 Nm) were applied about 13 axes corresponding to the three principal anatomic axes flexion/extension (FLE/EXT), left and right axial rotation (LAR/RAR), right and left lateral bending (RLB/LLB), and ten combined moment axes (e.g. EXT+LLB). Specimens were preconditioned with four cycles, and the data from the 5th cycle were recorded. Bending stiffness (slope of the linear least-squares fit), range of motion (ROM) (rotation at maximum moment), and neutral zone (NZ) (rotation between linear best fit lines at zero moment). Theoretical values for each biomechanical property were calculated about each combined moment axis using a linear combination of the principal values. To determine whether statistically significant differences occurred among the principal axes, the mean stiffness, ROM, and NZ were compared using a repeated measures ANOVA with a Tukey post-hoc test. To determine if the values of the combined axes could be predicted, experimental values for each combined axis were compared to the theoretically predicted values with a paired t-test. The level of statistical significance was set to 0.05.

RESULTS:
The biomechanical properties about the principal anatomic axes were similar, but had a significant dependence on the load direction. In general, the mean bending stiffness was lowest (and the ROM and NZ highest) for flexion and then extension, followed by axial rotation and lateral bending (e.g. Figure 1). For bending stiffness, flexion (FLE: 1.6±0.2 Nm/º) was significantly lower than extension (EXT: 1.8±0.3 Nm/º), right axial rotation (RAR: 2.0±0.3 Nm/º), left axial rotation (LAR: 2.0±0.2 Nm/º), left lateral bending (LLB: 2.1±0.3 Nm/º), and right lateral bending (RLB: 2.2±0.4 Nm/º). The stiffness in EXT was also significantly lower than RLB. The results were opposite for range of motion: FLE was significantly higher than LLB, RLB, LAR, and RAR. For NZ, FLE was significantly higher than LAR and RAR.

The differences between experimental and theoretically predicted values of the combined axes varied with the biomechanical properties. For ROM and NZ, there were no statistically significant differences between the experimental and theoretical values. However, the theoretically predicted stiffness values significantly overestimated the experimental stiffness values about the following moment axes: FLE+LLB, LAR+FLE, FLE+RAR, LAR+RAR+RLB, and RAR+FLE+RLB, while LLB+LAR+EXT, LAR+RLB, and RAR+LLB were significantly underestimated by the theoretical predictions.

DISCUSSION:
This is believed to be the first report on the biomechanical properties of the human disc about axes other than the three principal anatomic axes. Despite the asymmetrical shape of the human lumbar disc we found that the mechanical bending properties in axial rotation were not different than those in lateral bending. The most significant differences were due to an asymmetry between flexion and extension.

Linear combination of the principal anatomic axis components was able to predict the biomechanical properties about the majority, but not all of the combined axes. While this difference was primarily associated with flexion, the lower stiffness values of flexion are not sufficient to explain all of the differences. The differences in flexion and extension have also been reported by others and have previously been attributed to differences in the mechanical properties of the anterior longitudinal ligament (ALL) and posterior longitudinal ligament (PLL), rather than the disc itself [1,2].

While this study was motivated by the lack of data on the multidirectional mechanical properties of the human disc, it should be noted that this study is limited. We tested the functional spinal unit without posterior elements, and we anticipate that the findings reported here would not be consistent when testing the intact functional spinal unit. Additionally, the effect of age-related degeneration on the biomechanical properties may affect the results.

The multi-directional bending properties of the human intervertebral disc were determined. A simple linear combination of the principal anatomic components was unable to predict the bending properties in all of the directions tested, reinforcing the complexities of the human spine and the need for further multi-directional experimental testing.

REFERENCES:

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