THE IMPACT OF COMPRESSIVE LOAD MAGNITUDE ON THE IN-VITRO NEUTRAL ZONE RANGE AND PASSIVE STIFFNESS DURING A FLEXION-EXTENSION RANGE OF MOTION TEST

Mamiko Noguchi, Chad E. Gooyers, Michael W.R. Holmes, Jack P. Callaghan
Department of Kinesiology, University of Waterloo, Waterloo, ON, CA
email: mnoguchi@uwaterloo.ca

INTRODUCTION
The neutral zone, defined as the region of minimal passive stiffness [1], has been used to standardize the testing posture of functional spinal units (FSU) for in-vitro biomechanical studies. Typically, this region is determined experimentally through range of motion (ROM) tests, from which the applied moment and measured angular displacement are used to define the FSU’s passive stiffness. However, there is currently no standardized protocol that exists regarding the magnitude of compressive load that is applied during these tests [2]. As such, it has become increasingly difficult to make comparisons across studies since FSU test postures are typically defined using the experimental moment-angle data. The purpose of this study was to examine the impact of compressive load magnitude on passive flexion-extension (PFE) stiffness and neutral zone range. Considering previous research [3], it was hypothesized that increasing the magnitude of the compressive load would significantly change the passive stiffness of an FSU, resulting in different range of neutral zone.

METHODS
Twenty-one porcine cervical FSUs (12 c34, 9 c56; mean age = 6 months), each consisting of two adjacent vertebrae and the intervening IVD, were excised. Each FSU received four repeats of a PFE ROM test with varying magnitudes of compressive load (10, 300, 900, 1800 N), applied in a randomized order. Using an independent servomotor (AKM23D; Danaher Motion, Radford, VA, USA) connected in series with a torque cell (T120-106-1K, SensorData Technologies Inc., Sterling Heights, MI, USA), three complete PFE cycles were applied at a rate of 0.5 degrees per second. Throughout each test, the applied moment (Nm) and angular displacement (degrees) were sampled at 15 Hz. Using methods previously described [4], the first derivative of a fourth-order polynomial fit to the PFE moment-angle data was used to establish the range of each FSU’s neutral zone. Three dependent measures were compared across loading conditions: (i) the neutral zone range (i.e. flexion limit – extension limit; degrees), (ii) the difference in the flexion limit angular displacement between the 10N and the 300N, 900N, and 1800N testing conditions within each specimen (degrees), and (iii) neutral zone passive stiffness (Nm/degree); described by the slope of a linear fit to the angle-moment data within the boundaries that defined the neutral zone.

RESULTS
Increasing the magnitude of the applied compressive load significantly decreased the range of the FSU neutral zone, while increasing passive stiffness (Table 1). Specifically, the neutral zone range was reduced by 41% and 26% when the magnitude of compressive load was increased from 10N to 300N and from 300N to 1800N respectively. Moreover, neutral zone passive stiffness increased by 82% from the 900N to 1800N testing conditions. The mean changes in the flexion limit from 10N to each compressive load tested were within ±1°, where the 900N condition showed the largest mean change of +0.56° (SD 0.72).

DISCUSSION & CONCLUSIONS
Based on the results of this study, it is recommended that in-vitro spine biomechanics studies employ a standardized compressive load magnitude when conducting PFE tests. A standardized compressive load is particularly important when defining flexed and extended postures based on the specimen’s neutral zone. These findings are in accordance with previous research [3], in which the range of an FSU’s neutral zone was significantly reduced and the passive stiffness within this range significantly increased with an increase in compressive load. The neutral zone flexion limit (calculated for each FSU across different compressive load magnitudes) varied less than ±1°, indicating that the extension limit differs due to a shift in the zero-moment position depending on the compressive load magnitude. Therefore, conducting PFE tests with a compressive load that is standardized to the ultimate compressive failure tolerance of the FSU [5] may be appropriate when only the flexion limit is of concern for the test paradigm.

REFERENCES

ACKNOWLEDGEMENTS
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Table 1: Neutral zone range and passive stiffness.

<table>
<thead>
<tr>
<th>Dependent Measure</th>
<th>10</th>
<th>300</th>
<th>900</th>
<th>1800</th>
</tr>
</thead>
<tbody>
<tr>
<td>(degrees)</td>
<td>6.74±(1.10)</td>
<td>4.01±(0.56)</td>
<td>3.30±(0.32)</td>
<td>2.96±(0.54)</td>
</tr>
<tr>
<td>Passive stiffness (Nm/degree)</td>
<td>0.03±(0.006)</td>
<td>0.06±(0.04)</td>
<td>0.17±(0.04)</td>
<td>0.31±(0.06)</td>
</tr>
<tr>
<td>Flexion limit difference (degrees)</td>
<td>---</td>
<td>-0.53(0.59)</td>
<td>0.56(0.72)</td>
<td>0.27(0.77)</td>
</tr>
</tbody>
</table>

Note: Different superscript letters are significantly different (p < 0.05)