A Comparison of Testing Protocols for the Evaluation of Spinal Biomechanics
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Introduction

Back pain is the leading cause of disability worldwide, affecting a tenth of the world population and costing €500 million per annum to the NHS alone; possible treatment options include implantation of spinal devices [1]. Consequently, a substantial body of research has arisen aimed at investigating the biomechanical behaviour of the spine [2], typically focusing on a single isolated disc (ISD) specimen.

Two approaches have been employed to experimentally investigate the behaviour of ISDs; the flexibility and stiffness protocols [3,4]. For purely elastic specimens the two tests are predicted to be equivalent, however it remains to be demonstrated that this holds true for non-elastic specimens; this is the aim of the present study.

Materials and Methods

A synthetic non-elastic ISD was subjected to the two protocols using a custom made 6 degrees of freedom spine simulator, presented in Figure 1 [4]. A cross-section of the model ISD, with all its components is also shown in Figure 1 [6].

Results

A qualitative comparison was performed on the shape of the load-displacement curve. The data is presented in Figure 3 for two axes. The load-displacement characteristics from the two protocols are different, especially in anterior-posterior and lateral shear, where the curve was much narrower for tests performed under the stiffness protocol.

Discussion and Conclusion

This study has shown that there is a significant difference between the data produced by the flexibility and the stiffness protocols. The boundary conditions greatly affect the load displacement behaviour of a specimen, therefore this may be an important reason for the different results.

This important finding demonstrates the need to standardise the testing procedures used in spinal biomechanical investigations, to ensure comparisons can be easily made across laboratories in the future.

This study has demonstrated there is a significant difference between the data produced by the two main testing protocols used in the spinal model: flexibility and stiffness.

Table 1: Displacement amplitudes applied to the specimen during the flexibility protocol, for anterior-posterior shear (TX), lateral shear (TY), axial compression (TZ), lateral bending (RX), flexion-extension (RY), and axial rotation (RZ).

<table>
<thead>
<tr>
<th>TX (mm)</th>
<th>TY (mm)</th>
<th>TZ (mm)</th>
<th>RX (deg)</th>
<th>RY (deg)</th>
<th>RZ (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.5</td>
<td>0.35</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 2: Load amplitudes applied to the specimen during the flexibility protocol, for the loads in anterior-posterior shear (FX), lateral shear (FY), axial compression (FZ), lateral bending (MX), flexion-extension (MY), and axial rotation (MZ).

<table>
<thead>
<tr>
<th>Load (N)</th>
<th>FX (N)</th>
<th>FY (N)</th>
<th>FZ (N)</th>
<th>MX (Nm)</th>
<th>MY (Nm)</th>
<th>MZ (Nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 N</td>
<td>34.0</td>
<td>27.5</td>
<td>112.5</td>
<td>2.3</td>
<td>2.3</td>
<td>6.0</td>
</tr>
<tr>
<td>250 N</td>
<td>41.0</td>
<td>33.5</td>
<td>235.0</td>
<td>4.0</td>
<td>4.5</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Figure 1: Diagram of the spine simulator, a spinal segment, and the synthetic model.

The flexibility protocol is an unconstrained test where the specimen can move freely around its axes to minimise the loads acting on it. In contrast, the stiffness protocol constrains the specimen, preventing it from moving by imposing boundary conditions [6]. Both are represented in Figure 2.

Figure 2: A representation of the stiffness and the flexibility protocols.

The specimen was first subjected to a stiffness protocol characterised by the displacements given in Table 1. The resulting loads (Table 2), were applied to the specimen when subject to the flexibility protocol.

Table 3: Comparison of the six main diagonal terms of the stiffness, with and without preload. Values in italics denote no significant difference (p > 0.05).

<table>
<thead>
<tr>
<th>TX</th>
<th>TY</th>
<th>TZ</th>
<th>RX</th>
<th>RY</th>
<th>RZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 N</td>
<td>0.053</td>
<td>0.051</td>
<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>250 N</td>
<td>0.002</td>
<td>0.003</td>
<td>0.006</td>
<td>0.016</td>
<td>0.337</td>
</tr>
</tbody>
</table>

Similarly, the area enclosed by the load-displacement curves was significantly different when tests were performed with (p = 0.037) and without (p = 0.000) preload. In general there was a trend for the hysteresis area to be larger when the specimen was tested under the flexibility protocol.

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References