FACET LOADS OF HUMAN LUMBAR SPINE IN AXIAL ROTATION: AN IN VITRO BIOMECHANICAL STUDY USING EXTRA-ARTICULAR STRAINS

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The main biomechanical functions of facet joints in lumbar spine are to guide segmental motion and to share loading, especially in axial rotation and extension. For example, axial rotation causes the contralateral facet joint to be compressed. Despite this rather elementary concept of facet joint function, there is little information on load in the facet joint during axial rotation. A lot of effort has been made to understand facet loading of lumbar spine with intact segment or following surgical intervention. The earlier studies used pressure-sensitive film placed between the two contact surfaces by cutting the facet capsules. The alternative method keeping the facet capsule intact without intervention to the facet joints was the extra-articular strain technique proposed by Buttermann. The facet process was modeled as a cantilever beam. The facet load was determined by strain of three gauges on the ipsilateral facet joint. We recent found that in human lumbar spine strains coupled between both sides of facets, which was not investigated in the previous studies. Moreover, we proposed a new model to analyze facet loads in circumstance of coupling effect of strain on both sides. The objective of the present study is to analyze forces in both sides of facet joints of human lumbar spine in axial rotation with and without a follower preload using extra-articular strain. Accuracy is evaluated and verified by contact load measurement using the pressure-sensitive sensors on cadaveric lumbar spine specimens.

Methods
Ten fresh lumbar spine specimens from L2 to L5 were used in this study. Ten uniaxial strain gauges (Tokyo Sokki Kenkyujo, Tokyo, Japan) were bonded to the external surface of the left and right inferior facets of L3 similar to the previous method (Figure 1). Flexibility tests were performed on each intact specimen. A pure moment of 7.5Nm was applied to the specimen in axial rotation in three cycles with and without the presence of a compressive follower preload of 600N. Next, two thin films of electroresistive pressure sensors (Tekscan 6900 Quad Sensor) were lubricated and inserted into the joint surfaces following the capsule cut. The flexibility test was repeated. Strain, contact forces of the Tekscan sensors and the position of each vertebra was recorded in the flexibility test. Following, each specimen was sectioned at L3-L4 level for calibration of facet load. The inferior facet surfaces of L3 vertebra were exposed and were mapped using a grid of 16 points. A known force was applied to all points on the left and right facet joint surfaces, respectively. Finally, in order to validate this model, strain were recorded when a known forces was applied randomly to all points on the left and right facet joint surface, respectively.

A bilateral model was used to analyze facet loads from the strain in the flexibility test, i.e., magnitude and location of the resultant contact force in the facet joint. Compressive loads in the facet joints at peak moment in axial rotation were considered. Three-way ANOVA was used to analyze the facet loads under different sides (Left and right facet joints), status of specimen (Intact and capsule cut) and follower preload (0N and 600N). Paired T-test was used to compare facet loads measured by the strain and the Tekscan, and between sides. The significant difference level was set at 0.05.

Results
Both sides of facet joints were subjected to 70N compressive force under 7.5Nm moment in axial rotation and 600N follower preload. Without follower preload, the facet load was higher in the right facet joint, showing asymmetric between sides (Table 1). There was no significant difference of facet loads between left and right sides, with and without follower preload, and between the intact and the capsule cut status. The locations of the facet loads were quite symmetric between two facet joints, and in one-quarter of lateral and inferior region of facet joint surfaces. The location shifted laterally following the capsule cut, as well as medially with follower preload (Figure 2). The facet loads was predicted with 14% accuracy in the inferior region, which was better than that in the superior region with 20% and 17% in the left and right facets, respectively. Note of that in the region most facet loads located in axial rotation, the accuracy of model was the highest, with 9% and 4% in the left and right side, respectively. Comparing to the facet loads measure by the Tekscan, the facet loads predicted by the strain is averagely higher, and was significantly higher only in the right facet following capsule cut (p<0.018). Difference between them ranged from 45% to 90%.

Discussion
In the present study, the strain coupling between two sides could be as high as 30%. It is not suitable to determine the facet loads of human lumbar spine by the ipsilateral strain as the previous method. We used a general model to analyze facet load in case of strain coupling. The accuracy of facet load is depended on the location of the load, and affected by the extent of strain coupling. The strain technique appears to offer the extent of facet loads in axial rotation and is able to address facet load change under different loading profiles and following spinal column change due to surgical techniques and degenerative diseases.

Reference

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Table 1: Contact force of L3-L4 facet joints under 7.5Nm moment in axial rotation

<table>
<thead>
<tr>
<th>Method</th>
<th>Follower</th>
<th>Left facet</th>
<th>Right facet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain</td>
<td>0N</td>
<td>74±18</td>
<td>64±21</td>
</tr>
<tr>
<td></td>
<td>600N</td>
<td>70±20</td>
<td>62±21</td>
</tr>
<tr>
<td>Tekscan</td>
<td>0N</td>
<td>--</td>
<td>56±17</td>
</tr>
<tr>
<td></td>
<td>600N</td>
<td>--</td>
<td>48±17</td>
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</tbody>
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Figure 1. The flexibility test in axial rotation (Left) and posterior view of the specimen (Right). Ten strain gauges were bonded the posterior aspects L3 inferior facet processes. Two electroresistive pressure films (Tekscan) were inserted into the facet joints following resection of the capsules.

Figure 2. Locations of the facet loads in axial rotation on the surfaces of L3-L4 facet joints.

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