INTRODUCTION: Segmental instability of the lumbar spine is a common cause of low-back pain and may result from bony or ligamentous abnormalities. However, the term instability is not well defined and diagnosis is often based on imprecise radiographic findings. Various methods exist for determining in vivo motion in the transverse and sagittal planes, however few accurate and objective methods for measurement of in vivo axial rotation are available. The most common method for determining axial rotational motions involves the use of biplanar radiographs, which is prone to errors due to the inherent inaccuracy involved in precisely locating the same anatomic landmark in different radiographic views. This method also gives only an approximate true representation of actual axial rotations. Various methods have been developed that can more accurately measure vertebral body rotational motions. Rogers et al. used magnetic resonance scans to measure axial rotation of a phantom vertebral body and found the method to be accurate and reliable, but it produced only 2D measurements. Since actual spinal motion is 3-D, spinal instability may include significant changes in coupled motions, which cannot be measured using a planar technique. Lim et al. developed a non-invasive method for determining 3-D motion of cervical vertebrae in vivo by calculating the principle moments of inertia and principle axes of rotation from serial computed tomography scans. However, the precise assessment of complex 3D spinal motions remains difficult, especially in vivo. Previous in vivo methods have relied on voluntary efforts from the patient, which can lead to a high variability in the motions produced. Passive motion corrects this variability, however, with the scan time involved with CT scans, a displacement control is necessary to ensure a constant position of the spine. This requires that fixation is achieved both above and below the level at which rotation takes place. Care must be taken when such restraint is used to ensure that coupled motions are still allowed to take place. We have designed a custom device that allows us to exert a known passive external rotation on the lumbar spine without limiting coupled motions. Data obtained using this device in a CT scanner allows for the 3-D measurement of lumbar segmental motion in vivo. The goal of the present study was to determine the feasibility and accuracy of this method in vivo.

METHODS: CT scans (GE Somatom) of seven volunteers without low-back pain (ages 20-40, 4 male, 3 female) were obtained in five positions; neutral, rotated left and right 30° and rotated left and right 50° with each subject lying supine (IRB approval #0004280). The thoraco-lumbar rotation control apparatus (TRCA) was specifically designed to induce rotations solely in the lumbar spine by controlling shoulder and chest rotation while constraining hip and pelvis motion (Fig. 1). This was achieved by placing the subject supine upon two separate beds, one for the hips and legs and the other for the upper body leaving the lumbar spine free to move. The height of both beds was carefully controlled to ensure the axis of rotation was aligned with the vertical axis of the spine. Each bed was firmly attached to a rigid plastic bed to ensure each bed remained in place relative to the other and to the gantry of the CT scanner during scanning. The hips and upper thighs were secured to the TRCA using two high strength velcro straps placed just below the level at which rotation takes place. Care must be taken when such restraint is used to ensure that coupled motions are still allowed to take place. We have designed a custom device that allows us to exert a known passive external rotation on the lumbar spine without limiting coupled motions. Data obtained using this device in a CT scanner allows for the 3-D measurement of lumbar segmental motion in vivo. The goal of the present study was to determine the feasibility and accuracy of this method in vivo.

RESULTS: Rotation of the chest to the left 30° and 50° resulted in sacral flexion extension moments of 1.0° ± 0.9° and 1.8° ± 2.5° respectively. Rotation to the right 30° and 50° resulted in sacral extension moments of 0.1° ± 0.9° and 0.4° ± 1.1° respectively. Rotation to the left 50° produced 0.3 ± 2.2 mm anterior, 7.2 ± 4.1 mm lateral, and 0.5 ± 3.5 mm inferior sacral translations, while rotation to the right 50° produced 0.8 ± 0.9 mm anterior, 1.0 ± 2.8 mm right lateral, and 0.2 ± 1.7 mm superior sacral translations, while rotation to the right 50° produced 1.0 ± 1.6 mm anterior, 4.0 ± 0.4 mm right lateral, and 0.2 ± 1.8 mm inferior sacral translations. The average axial rotations of L1 and the sacrum with respect to neutral are shown in Table 1.

DISCUSSION: In vivo spinal motion can be measured by fixing one end of the motion segment and applying constant load at the opposite free end. This setting does not constrain the coupled motion of the motion segments and is described as a flexibility experimental model by Panjabi. However, several limitations exist to apply this model to in vivo study. In the motion analysis using a CT scanner, application of the consistent load is not suitable due to the possible increase of the deformation during CT scanning. Therefore, the chest was firmly constrained and a known torsional angle was applied to the upper trunk and rotation was constrained at the hip joint to create torsional motion in the spine in the present study. The results show that the TRCA can constrain sacral rotational motions reasonably well, while still allowing coupled motions. The sacral rotation of approximately 10% of the external rotation appears to be a result of soft-tissue deformation, which cannot be avoided. However, the movement of the sacrum will not affect the motion analysis of the lumbar spine because the motion of each vertebra can be calculated with respect to the sacrum. This method allows for a more complete measurement of actual in vivo spinal motions than any previous method and in so doing, this method may allow for a more clear definition, and therefore, diagnosis of spinal instability.

Table 1: Average rotations of L1 and sacrum with respect to neutral.

<table>
<thead>
<tr>
<th></th>
<th>Left 30°</th>
<th>Left 50°</th>
<th>Right 30°</th>
<th>Right 50°</th>
</tr>
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<tbody>
<tr>
<td>L1</td>
<td>9.2° ± 1.6°</td>
<td>16.7° ± 2.4°</td>
<td>9.6° ± 2°</td>
<td>17.2° ± 1.6°</td>
</tr>
<tr>
<td>Sacrum</td>
<td>3.2° ± 1.1°</td>
<td>8.7° ± 1.9°</td>
<td>3.3° ± 0.7°</td>
<td>7.2° ± 1.1°</td>
</tr>
</tbody>
</table>

REFERENCES:

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