INTRODUCTION

In 2008 413,171 spinal fusion surgeries were performed [1]. The various reasons for the surgery include spondylothesis, spinal stenosis, and herniated discs among others [2]. These conditions can cause the intervertebral discs, cartilaginous shock absorbers, to degenerate. Ultimately, this can cause the vertebral bodies to rub on each other, causing pain and discomfort. Spinal fusion surgery is the process of fusing two vertebrae that are impeding on each other together to prevent motion between the two. To do this a surgeon creates a bone graft between the two vertebrae [3]. While the surgery does help to alleviate spinal pain, the fusion can cause increased stress and degeneration at vertebrae above and below the site [3].

Current researchers have trouble studying dynamic movement in 3-D [4]. The standard is to capture two 2-D x-ray images, one at no amount of flexion and one at full flexion. This allows for the overall range of motion in the flexion-extension plane to be quantified [4]. Being able to view intervertebral movement in 3-D dynamically would allow for the quantification of range of motion (ROM) in every plane – sagittal, frontal, and axial, while also being able to view how the motion changes throughout the course of the dynamic movement.

The current tool used to model 3-D dynamic intervertebral kinematics by the Orthopaedic Biodynamics Laboratory is a Dynamic Stereo X-Ray (DSX) system. The DSX system consists of two bi-plane x-ray systems emitting x-rays at a rate of 30 frames per second. At this frame rate more x-ray frames are able to be captured during a particular amount of time, and consequently a dynamic movement is able to be captured. The bi-plane x-ray system combined with a model based tracking software allows for the capturing of the 3-D in vivo dynamic process [4].

OBJECTIVE

With a limited amount of 3-D intervertebral dynamic data existing, further investigation using the DSX system needed to be performed to analyze the effect spinal fusion surgery required spinal conditions have on a person’s intervertebral lumbar kinematics. The intention of the study was to create 3-D dynamic models of subjects both requiring and not requiring spinal fusion surgery, henceforth referred to as symptomatic and asymptomatic, respectively. The 3-D models would be analyzed to quantify the entire ROM of the lumbar spine and how each adjacent pair of vertebrae interacted dynamically in relation to each other.

HYPOTHESIS/SUCCESS CRITERIA

In order to be successful, the amount of 3-D modeled dynamic movement based on the DSX captured images needed to be maximized. This was based on the success of the model-based tracking, a process of using the x-ray images and CT scan modeled bones to replicate the dynamic movement captured. The basis of this was ensuring there was smooth dynamic movement by performing an eye test and limiting the rotational change in every plane for each individual vertebra to under 0.5° between each x-ray frame.

METHODS

11 subjects, a mix of symptomatic and asymptomatic, performed flexion-extension, lateral bending, twisting and static trials while being captured by the DSX system. A CT scan of the lumbar spine was taken for each subject. The CT scan was anonymized and loaded into Materialise Mimics. Materialise Mimics was used to outline and highlight each individual vertebra of the lumbar spine, L1 – L5. The end result produced 3-D models of all vertebrae of the lumbar spine. Each vertebra was exported into ImageJ image processing software, where the file format was converted to be compatible with the lab’s unique Model-Based Tracking software. The CT scan modeled vertebrae were then ran through Create Surface in which anatomical landmark markers were placed at their respective locations on the faces of the vertebral body, pedicles, and the superior and inferior articular processes. The landmarks created a coordinate system for each vertebra with axes in the anterior-posterior (AP), medial-lateral (ML), and superior-inferior (SI) directions. The modeled vertebrae were individually loaded into files organized by subject, movement, and trial number. These files were read into the Model-Based Tracking software. The CT scan modeled bones were both manually moved and assisted by the software to match each individual frame of the DSX captured sequence. The rotational movement about the AP, ML and SI axes of the vertebrae were automatically calculated. The movement needed to be manually corrected completion to ensure the rotational change in every direction between each frame was less than 0.5° and the modeled bone accurately matched its orientation in the x-ray images.

The Model-Based Tracking rotational results were loaded into a kinematics analysis file. The results combined with the coordinate system produced in Create Surface created 3-D models of the subject’s lumbar spine performing each individual dynamic movement trial and produced a data table of how each adjacent set of vertebral bodies moved rotationally and translationally about each other in each plane. Finally, for certain trials, the rotational and translational movements between the

IN VIVO LUMBAR MODELING

Zach Adgate
University of Pittsburgh Orthopaedic Biodynamics Laboratory
RESULTS
The 11 subjects performed 79 dynamic trials in total. With this, 395 vertebrae needed to be successfully tracked through Model-Based Tracking. Of these, 230 were successfully tracked through their dynamic trial, with only 1 subject’s flexion trial having the entire lumbar spine as well as sacrum tracked in its entirety. This subject’s flexion trial was both rotationally and translationally analyzed.

Table 1: Each pair of vertebrae’s translation about each other in a flexion trial.

<table>
<thead>
<tr>
<th>Plane</th>
<th>L1-L2 Trans. ROM (mm)</th>
<th>L2-L3 Trans. ROM (mm)</th>
<th>L3-L4 Trans. ROM (mm)</th>
<th>L4-L5 Trans. ROM (mm)</th>
<th>L5-S1 Trans. ROM (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sagittal</td>
<td>3.50</td>
<td>5.151</td>
<td>5.245</td>
<td>4.751</td>
<td>4.611</td>
</tr>
<tr>
<td>Frontal</td>
<td>0.801</td>
<td>1.044</td>
<td>0.795</td>
<td>0.558</td>
<td>2.424</td>
</tr>
<tr>
<td>Axial</td>
<td>1.123</td>
<td>0.810</td>
<td>1.22</td>
<td>0.700</td>
<td>5.563</td>
</tr>
</tbody>
</table>

DISCUSSION
Overall, for all 11 subjects 230 out of 395 vertebrae were successfully tracked. The 230 were the maximum amount possible to track. Of those 230 the rotational changes between each frame were limited to under 0.5° for each frame of the DSX captured x-rays. Only one asymptomatic subject’s flexion trial was successfully tracked L1-S1. This showed the ROM of a flexion rotation for each pair of vertebrae was the greatest, with limited ROM for the bending and twisting rotations. For L1-L2, the ROM for flexion was around 8°, L2-L3 around 12°, L3-L4 around 14°, L4-L5 around 11°, L5-S1 around 12.5°, and the entire lumbar spine L1-S1 had a flexion ROM of around 55°.

The translational ROM for each pair of vertebrae was always greatest in the sagittal plane, or in the AP direction, for the same flexion trial. L5-S1 showed different results because of the way S1 is oriented in the body, and its corresponding coordinate system.

Moving forward the amount of subject’s with their entire lumbar spine L1-S1 needs to be tracked, modeled, and analyzed. It is difficult to track for certain subjects because muscle and fat can distort the x-ray images so they are not visible. New x-ray techniques need to be implemented to work around this.

Further in the study we will compare asymptomatic patients to symptomatic patients and subjects pre- and post-surgery.

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REFERENCES