A COMPUTATIONAL INVESTIGATION OF MINIMALLY INVASIVE SPINE SURGERY

1John Rasmussen and 2Sten Rasmussen
1Department of Mechanical and Manufacturing Engineering, Aalborg University, Denmark; email: jr@m-tech.aau.dk
2Orthopaedic Surgery Research Unit, Aalborg University Hospital, Denmark

SUMMARY
The paper compares the effect of minimally invasive spine surgery (MISS) with traditional open spine surgery (TOSS) by means of a detailed musculoskeletal model. The model compares four different fusions performed with MISS and TOSS respectively. It is concluded that the MISS approach leads to less muscular load in gait compared with the TOSS approach.

INTRODUCTION
MISS has been used for more than a decade [1]. The reasoning is the perception that a gentle surgery is more beneficial for the patient, especially because TOSS has several reported drawbacks including blood loss, muscle pain and infection. Minimally invasive insertion systems are designed to minimize the approach-related morbidity of traditional lumbar pedicle fixation. A major part of reducing morbidity might be the preservation of the tendon attachment of the muscle. The aim of this study was to investigate the implication of preserving tendon attachment using MISS compared to TOSS.

METHODS
The computational investigation is performed with the AnyBody Modeling System version 5.2 (AnyBody Technology, Aalborg, Denmark) [2] and its associated model library, the AnyScript Managed Model Repository, version 1.5. The library allows for composition of ad-hoc models by combination of individual body parts, such as a spine and a pelvis, but the present investigation used the entire body comprising a spinal part [3,4], upper extremities [5] and lower extremities [6], totaling more than 1000 independently activated muscle-tendon units. The motivation for including all the details of the lower and upper extremities is the possibility that they might influence the spine through muscles such as psoas major and trapezius.

The spine model comprises the pelvis, sacrum, L5 through L1 and a thoracic segment, and it was validated against disk pressure data [7] for a variety of different postures and working tasks [8]. The kinematics of the spine model is controlled by imposition of the relative flexion/extension, lateral flexion and rotation angles between the thorax and the pelvis. These angles are automatically distributed by the model among the lumbar vertebral joints. The stiffness of these joints can consequently be controlled in the model, effectively allowing for fusion of individual joints, thus requiring neighboring joints to assume a larger fraction of the total pelvis-thorax angle.

Figure 1: The musculoskeletal model of normal gait used for the simulation.

The model is subjected to the basic activity of daily living, namely normal gait. The gait data were recorded with a male subject, 26 years of age, stature of 1.73 m and body mass 62 kg. A Qualisys Oqus system (Qualisys AB, Gothenburg, Sweden) and ATM force platforms (AMTI, Watertown, Massachusetts, USA) were used to collect the data, which subsequently were stored on a C3D file and imported into the AnyBody Modeling System for musculoskeletal analysis.

The following scenarios are simulated:
- Baseline: A case in which all muscles are intact and the motions of all lumbar joints are unencumbered.
• L5S1MISS: Fusion of L5 and S1 without any muscle injury, i.e. the MISS case.
• L5S1TOSS: Fusion of L5 and S1 with all the muscles originating or inserting on these two vertebrae disabled, thus simulating the TOSS case.
• L4L5MISS: Fusion of L4 and L5 without any muscle injury, i.e. the MISS case.
• L4L5TOSS: Fusion of L4 and L5 with all the muscles originating or inserting on these two vertebrae disabled, thus simulating the TOSS case.

The results of the simulations are summarized in Table 1.

CONCLUSIONS
The model indicates that the muscle preservation obtained by MISS leaves the patient with significantly better muscular functionality compared with TOSS. The investigation has only considered the muscular effect of the two approaches, while remaining parameters such as joint forces or loads on the fused joint remain for future investigation.

REFERENCES

Table 1: Summary of increase of maximum muscle activation in percentage-points for each muscle.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Max. increase of muscle activation</th>
<th>In muscle</th>
</tr>
</thead>
<tbody>
<tr>
<td>L5S1MISS</td>
<td>12%</td>
<td>psoas major</td>
</tr>
<tr>
<td>L5S1TOSS</td>
<td>12%</td>
<td>psoas major</td>
</tr>
<tr>
<td>L4L5MISS</td>
<td>14%</td>
<td>multifidus</td>
</tr>
<tr>
<td>L4L5TOSS</td>
<td>25%</td>
<td>obliquus internus</td>
</tr>
<tr>
<td>L3L4MISS</td>
<td>4%</td>
<td>psoas major</td>
</tr>
<tr>
<td>L3L4TOSS</td>
<td>32%</td>
<td>obliquus internus</td>
</tr>
<tr>
<td>L4S1MISS</td>
<td>12%</td>
<td>psoas major</td>
</tr>
<tr>
<td>L4S1TOSS</td>
<td>14%</td>
<td>erector spinae</td>
</tr>
</tbody>
</table>

Table 1 and Figure 2 clearly show that MISS is preferable to TOSS from the point-of-view of muscle activation, except for the case of L5S1 fusion. This is really not surprising considering the fact that all of the muscle fascicles originating from or inserting on the affected vertebrae are sacrificed in TOSS. The need for increased muscle activation does not come from the requirement to support the joint that was fused; the fused joint is supported in the model and in practice by the device and fusion of bone. However, because of the complex configuration of the muscles in the lumbar spine, many of the sacrificed muscle fascicles cross the joints to the adjacent vertebrae. These joints must now be balanced by the much fewer fascicles crossing multiple vertebrae.