ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

A COMPUTATIONAL INVESTIGATION OF MINIMALLY INVASIVE SPINE SURGERY

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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.

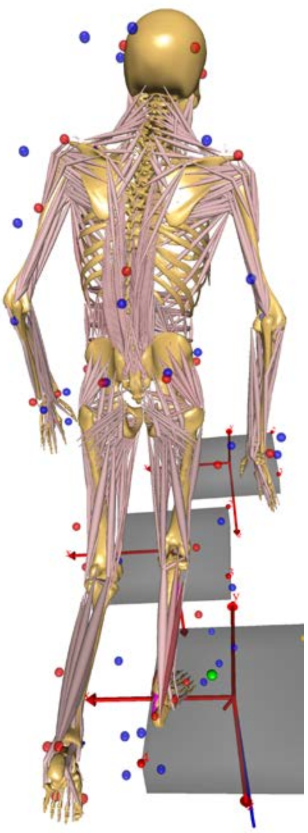

Figure 1: The musculoskeletal model of normal gait used for the simulation.

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.
- L3L4MISS: Fusion of L3 and L4 without any muscle injury, i.e. the MISS case.
- L3L4TOSS: Fusion of L3 and L4 with all the muscles originating or inserting on these two vertebrae disabled, thus simulating the TOSS case.
- L4S1MISS: Double fusion of L4 with L5 and L5 with S1 without any muscle injury, i.e. the MISS case.
- L4S1TOSS: Double fusion of L4 with L5 and L5 with S1 with all the muscles originating or inserting on these three vertebrae disabled, thus simulating the TOSS case.

The analysis of the gait cycle was performed in a total of 197 steps and the active state of each muscle was computed in each step. The maximum activation of each muscle over the cycle was then extracted for each case. Subsequently, the maximum Baseline activation was subtracted from the maximum activations of each of the scenarios L5S1MISS, L5S1TOSS, L4L5MISS, L4L5TOSS, L3L4MISS, L3L4TOSS, L4S1MISS and L4S1TOSS, thus producing the increase of maximum activation in percentage-points for each muscle for each surgical scenario.

RESULTS AND DISCUSSION

The results of the simulations are summarized in Table 1. Figure 2 compares the MISS scenarios with their TOSS counterparts.

Table 1: Summary of increase of maximum muscle activation in percentage-points in the different simulated scenarios compared with the Baseline scenario.

Scenario	Max. increase of muscle activation	In muscle
L5S1MISS	12%	psoas major
L5S1TOSS	12%	psoas major
L4L5MISS	14%	multifidus
L4L5TOSS	25%	obliquus internus
L3L4MISS	4%	psoas major
L3L4TOSS	32%	obliquus internus
L4S1MISS	12%	psoas major
L4S1TOSS	14%	erector spinae

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.

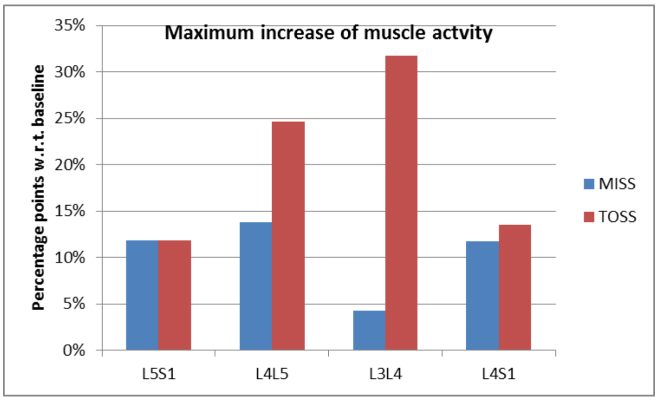

Figure 2: Comparison of the increases in maximum muscle activity in the gait cycle as a result of the surgery for MISS versus TOSS.

Additionally, the articulation of the adjacent joints is increased which causes the increase in muscle activation predicted for the MISS case.

It is remarkable that the case of L3L4 appears to be more sensitive to the TOSS approach than any of the other cases, including the double fusion L4S1, and that fusions with the TOSS approach at more proximal levels generally appear to affect the muscle activation more than distal levels. In the MISS approach, the tendency is the opposite. Another remarkable finding is that L4L5TOSS results in significantly more increase in muscular load than the more elaborate L4S1TOSS. This is because both procedures sacrifice muscles spanning L5S1 but only the L4S1 procedure provides force and moment stabilization of L5S1by fusion.

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.

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