VISCOELASTIC EFFECTS AT THE BONE-SCREW INTERFACE

Serkan İnceoğlu¹, Atilla Akbay¹, and Robert F. McLain²

¹ Spine Research Laboratory, Spine Institute, The Cleveland Clinic Foundation, Cleveland, OH, USA
² Dept. of Orthopedic Surgery, Spine Institute, The Cleveland Clinic Foundation, Cleveland, OH, USA

E-mail: inceogls@bme.ri.ccf.org

INTRODUCTION
Bone exhibits time-dependent behavior under external loading. The viscoelastic properties of cortical and trabecular bone have been well studied. It has been shown that the time-dependent effects can reduce mechanical performance of bone as drastically as do cycle-dependent effects via micro-fractures (Carter and Caler, 1985). In addition, there are very limited information towards the viscoelastic properties of cadaveric bone and specially bone-screw interface. Pedicle screw fixation system is one the most commonly used stabilization methods in spinal surgery. Despite of its success, the failure of pedicle screw fixation through loosening has been, however, reported. Loss of fixation strength in screws prior to successful arthrodesis was believed to be due to micro-fractures via fatigue or bone loss in the proximity of the implant. However, there is no data available to assess the effects of viscoelastic properties of bone on its mechanical behavior. This study was designed to investigate the effects of stress relaxation phenomenon on the pullout performance of pedicle screw in human vertebra.

METHODS
For the study fourteen cadaveric thoracolumbar vertebral levels (T12-L4) were retrieved from three different donors. After DEXA-scanning for collecting bone mineral content (BMC) data, each specimen was instrumented with 6.5x40mm pedicle screws (Xia, Stryker Spine, New Jersey) according to the standard surgical procedure using appropriate surgical tools and instrumentation. After embedding, the specimens were secured into a material testing machine (MTS Alliance RT/10, MTS Corp., Eden Prairie, MN) using customized gripping fixtures. One of each screws at each specimen was withdrawn according to one of two pullout models, i.e., stress relaxation(SR) model and standard(S) model. In S-model pullout, screws were continuously pulled at a rate of 5mm/min whereas in SR-model pullout, screws were pulled stepwise manner, i.e., 0.5 mm actuator advancements and 1000 seconds rest period in between, until failure. The failure was defined as the highest load that the bone-screw interface could bear. Peak load, stiffness, displacement-to-failure(DtF), and energy-to-failure(EtF) data were calculated. The last two were calculated between 150N and failure point to exclude “toe-region”. The stiffness for SR-model was calculated using the peaks of the load-displacement curve in pre-failure region as shown in Figure 1b. Correlation and regression analysis were done between the BMC and parameters of interest. Normalization was, then, carried out when correlation coefficient (R²) was greater than 0.5. Two pullout models were compared using paired t-test in 95% confidence interval.
RESULTS
In the study, 28 pedicle screws were pulled. Statistical analysis showed correlations between BMC and peak load ($R^2=0.66$, $R^2=0.63$), DtF ($R^2=0.34$, $R^2=0.51$), EtF ($R^2=0.61$, $R^2=0.65$) in both SR-model and S-model, respectively. Due to lack of bone quality of the one of the donors, the stiffness calculations could not be done properly in SR-model. Therefore only nine specimens were used for stiffness calculations. No normalization was done on stiffness data due to lack of correlation ($R^2=0.32$ for SR-model, $R^2=0.17$ for S-model).

Statistical analysis showed that the peak loads (p<0.0001) and stiffnesses (p=0.04) in SR-model were lower than those in S-model. EtF was higher in SR-model than that in S-model (p=0.0004). There was no significant difference in DtF data between the groups (p=0.054).

Table 1: Results of pullout tests from both pullout models (stress relaxation and standard models) were presented (mean±SD). Except for the stiffness, all the data were normalized with bone mineral content (g).

<table>
<thead>
<tr>
<th></th>
<th>SR-model</th>
<th>S-model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Load (N/g)</td>
<td>305.7±51.5</td>
<td>387.1±64.9</td>
</tr>
<tr>
<td>Stiffness (N/mm)</td>
<td>1186.9±508.7</td>
<td>1650.5±597.7</td>
</tr>
<tr>
<td>DtF (mm/g)</td>
<td>0.136±0.046</td>
<td>0.179±0.043</td>
</tr>
<tr>
<td>EtF (Nmm/g)</td>
<td>537.3±88.7</td>
<td>477.2±74.9</td>
</tr>
</tbody>
</table>

SUMMARY
It is important to know the mechanical properties of the interface to prevent loss of implant purchase. The present results showed that stress relaxation phenomenon at the bone-pedicle screw interface altered mechanical behavior of the screw in cadaveric specimens by yielding lower ultimate strength and stiffness. These results coincided with previous studies conducted by using bovine model (İnceoğlu et al., 2004). This study provides information about the mechanics of the interface when a patient remains steady, i.e., sitting, sleeping, etc., during daily activities.

REFERENCES