Prediction of Pullout Strength of Pedicle Screw by Bone-Screw Gap and Impulse Testing

1Chou, W K; 2Cheng, S Y; 2Pao, J L; 2Chueh, S C; 3Weng, Y S; +1Wang, J L

1Institute of Biomedical Engineering, National Taiwan University, Taipei, Taiwan.
2Far-Eastern Memorial Hospital, Taipei, Taiwan.
3Industrial Technology Research Institute, Hsinchu, Taiwan.

Senior author: jlwang@ntu.edu.tw

INTRODUCTION:
Screw-rod type of spinal instrumentation is widely used in the treatment for spinal disorders, such as spine trauma, spondylolisthesis, disc disorders, and spine deformations. Screw loosness, particularly the pedicle screw, is one of the frequently observed failure of screw-rod type implantation. The consequence of screw looseness can be devastating and most of the time a revision surgery is needed, hence many new designs, coatings or surgery methods were developed for the screw to resist the fatigue loading. The screw looseness is because of the increased gap due to fatigue loading. Nevertheless, the quantitative link between the bone-screw gap and pullout strength is less studied. The standard mechanical method to decide the looseness of bone-screw interface is the pullout test. The pullout test is a destructive testing method; therefore, large specimen number is needed for the development of new screws or surgery methods. The dynamic frequency response, or more specifically, the resonant frequency, of impulse test can detect the compactness or looseness of a structure without damaging the specimens; hence may be a non-destructive method to determine the looseness of bone-screw interface. In this study, the purpose is in two-folds. First, to find the relationship between the screw pullout strength and gap of bone-screw interface; and second, to find the relationship between the screw pullout strength and the dynamic frequency response during impulse test.

MATERIALS AND METHODS:
Specimens: 30 human cadaveric thoracic spine vertebrae (T9–T12, age: 66±17 y/o, bone mineral density (BMD): 0.86±0.1 g/cm³) were divided into three groups, i.e., “intact”, “1 mm gap” and “2 mm gap group” (n=10 for each group). The averaged BMD of each group was not significantly different from each other (p=0.291). Pedicle screw (diameter: 6mm, length: 40mm, Zimmer GmbH, Winterthur, Switzerland) was inserted into each vertebra under the guidance of an experienced orthopedic surgeon. For the specimens in “1 mm group” and “2 mm group”, the bone-screw interface gap was created by fatigue loading (peak to peak: 20 to 200 N, 5 Hz) that vertically applied on the screw head. An LVDT was attached to the head of pedicle screw to detect the pedicle screw displacement. The displacement of LVDT was acquired as the gap between bone and screw. The fatigue loading was stopped until the target gap magnitude was reached (Fig 1). Procedures: Impulse test and pullout test were sequentially applied to each specimen. An accelerometer was attached to the pedicle screw to measure the pedicle screw acceleration while the pedicle screw subjected to the impulse loading. The impulse force magnitude was 50 N and the force contact time was 5 ms. Fourier transformation of the accelerations was performed to find the resonant frequency of pedicle screw (Fig 2). The pullout test was conducted to find out the pullout strength of pedicle screw. During the pullout test, the pedicle screw was axially pulled out at the speed of 5 mm/min. The maximum pullout force was recorded. Data analysis: The pullout strength of three groups was compared using independent t-test. The linear regression between the pullout strength and the resonant frequency was conducted to find its correlations. The significant level was set at p=0.05.

RESULTS:
The screw resonant frequency and screw pullout strength decreased significantly with bone-screw gap (p<0.00) (Table 1). The bone-screw resonant frequency and screw pullout strength of 2 mm gap group was lower, but not statistically significantly, than those of 1 mm gap group. The bone-screw resonant frequency was positively and linearly correlated to the pullout strength (Fig 3).

DISCUSSION AND CONCLUSION:
The bone-screw resonant frequency and pullout strength decreased as the gap between of the bone and screw increased. The increased gap between bone and screw interface results in the damage of surrounding tissue of pedicle screw. The damaged tissue decreases the interdigitation of screw and bone, thus decreases the screw pullout strength. This study showed 1 mm gap between bone and screw significantly decreases the pullout strength. It is clinically possible to calculate the bone-screw gap by the post surgery radiographs. Nevertheless, more frequently, the looseness of bone-screw interface is clinically examined by the presence or intensity of radiolucent line between the bone and screw interface. The link between physical gap of bone-screw interface and the intensity of radiolucent line can be further studied.

The non-destructive method, i.e. the impulse test in this study, showed the resonant frequency of bone-screw construct is highly correlated to the pullout strength. The non-destructive method can be useful to analysis the progression of screw looseness during fatigue loading, thus decrease experimental error and number of specimens.

Table 1. The biomechanical tests performed in each group

<table>
<thead>
<tr>
<th></th>
<th>Intact</th>
<th>1 mm gap</th>
<th>2 mm gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (kHz)</td>
<td>1.62 (0.23)</td>
<td>1.39 (0.22)*</td>
<td>1.29 (0.20)*</td>
</tr>
<tr>
<td>Pullout Strength (kN)</td>
<td>1.14 (0.24)</td>
<td>0.72 (0.46)*</td>
<td>0.66 (0.41)*</td>
</tr>
</tbody>
</table>

Value: mean (standard deviation), *significantly less than intact group

ACKNOWLEDGEMENT:
National Health Research Institute, Taiwan (NHRI-EX98-9733EI)
National Science Council, Taiwan (NSC 98-2221-E-002-007-MY3)