AXIAL CYCLIC AND FAILURE LOADING OF PEDICLE SCREWS

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INTRODUCTION

Screw loosening and pullout are common ways of fixation failure in clinic preventing fusion and causing pain. Standard pullout test is used to assess the mechanical behavior of the bone-screw interface. In the pullout test, the screws are placed in either synthetic or bone specimens and are withdrawn by applying an axial load at a constant rate. Although bone is known to be a viscoelastic material and thus produce a mechanical response to the loading depending on the application rate, it is still not clear if the bone-screw interface behaves similarly. Therefore, we designed this study to test the effects of loading rate on the mechanical performance of the pedicle screw in pullout.

METHODS

For this purpose, 20 conical pedicle screws (Xia, Stryker Spine, Allendale, NJ) with a size of 6.5x40mm were inserted into a foam material (Sawbones, Pacific Research Laboratories, Vashon, WA) with a density of 0.32 g/cc and axially cycled at four different rates, i.e., 0.1, 1, 5, 50 mm/min -and 1 mm/min again for diagnosis-, up to a pre-yield load (500 N) and pulled out. Then, another 40 of the same screws were inserted in foam blocks and immediately pulled out. The aforementioned loading rates were used for pullout tests, i.e., yielding 15 screws for each rate. Additionally, a lumbar bovine spine was cleaned of soft tissue and separated into vertebral levels (L1-5). Ten pedicle screws were inserted in 5 calf lumbar vertebrae according to the standard surgical technique. After instrumentation, the vertebral specimens were cut in half sagittally isolating each pedicle for testing. After embedding, one of each pair of screws in each calf specimen was pulled at a rate of either 0.1 or 50 mm/min after cycled axially at the rates of 0.1, 1, 5, 50 mm/min, sequentially, around a pre-yield load (500 N). All the testing was conducted using an MTS testing machine and custom adapters. The gripping fixtures were carefully adjusted so that there was no laxity in the system to allow cycling without losing the contact. Stiffness was calculated as the slope of the load-displacement curve in the interval of 50-450 N. The peak load was the highest load encountered during destructive testing.

RESULTS AND DISCUSSION

The results showed that the strength and stiffness were significantly affected by the loading rate. The stiffness at 1 mm/min was higher than that at 0.1 mm/min ($p<0.001$) and lower than that at 5 mm/min loading rate ($p<0.001$). The stiffness significantly dropped at the 50 mm/min ($p<0.05$) compared to the 5 mm/min in the foam group but it was still significantly higher than that at 0.1 mm/min ($p<0.001$). In bone group, the stiffness at the 5 mm/min rate was higher than those at the 0.1 mm/min ($p<0.05$) and 50 mm/min ($p<0.05$) but not 1 mm/min ($p>0.05$). The difference between the 0.1 mm/min and 50 mm/min loading rates was not significant ($p>0.05$). The peak load at the 50 mm/min rate was significantly higher than other loading rates ($p<0.01$) in the foam group except for the 1.0 mm/min ($p>0.05$). The peak load at 50 mm/min was significantly higher than that at 0.1 mm/min in the bovine group ($p<0.05$). The effects of loading rate on the hysteresis curves are shown in Figure 1.

The bone-screw interface usually exhibits completely different mechanical and viscoelastic behavior than bone alone. However, our results showed that the mechanics of the interface was significantly affected by the loading rate, as similarly to bone alone. The results also showed that the mechanical behavior of the foam-screw interface was similar to that of the bone-screw interface. However, the hysteresis behavior of the interface in the elastic region was surprisingly different from those of bone and foam and totally new to the current literature. The authors speculated that the data collected during the unloading phase of cycling could source from loading of different sites of the foam or bone threads and cause the load-displacement data to draw this unexpected curve. Further analysis needs to be conducted.

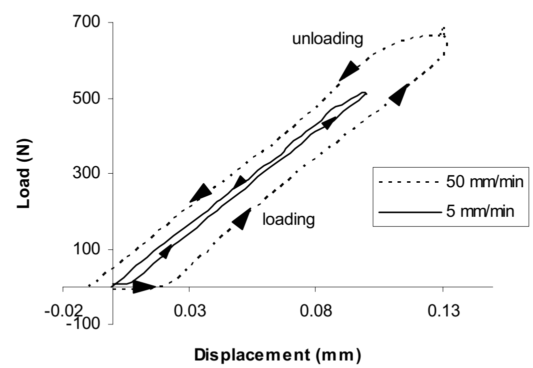

Figure 1: High loading rate caused increased hysteresis. The hysteresis behavior of the interface in pre-yield region was different than those seen in foam or bone. This unexpected trend of unloading curve might source from loading of other sites of the bone or foam threads.

CONCLUSIONS

This study investigated the axial cyclic behavior of a bone-screw interface in pre-yield load level at different rates for the first time in the literature. The results showed that the loading rate significantly affected the strength and stiffness of the interface. This suggests that for a fair comparison between screw pullout tests in the literature, the pullout rate needs to be matched. In the future, these results should be confirmed for other screw designs. The stress-strain behavior of a bone thread also needs to be investigated in a greater detail.

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