学位論文の要旨

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学位論文名	Relationship Between Thread Depth and Fixation Strength in Cancellous Bone Screw
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論文内容の要旨

INTRODUCTION

Screws are widely used as fixation devices for the surgical treatment of fractures. so even simple fractures require surgical fixation to reduce the rate of post-injury disability; in such cases, metal screws are more often used than screw-plate systems. Pull-out strength is one of the most important parameters to judge the fixation strength of a screw. Unfortunately, there is no known "gold standard" for bone screw shape, but the pull-out strength of screws tends to increase with a wider major diameter, narrower pitch, and deeper thread depth.To our knowledge, no empirical experiments have been reported with only screw depth as a variable. We hypothesized that screw depth and screw fixation strength are positively correlated.

Therefore, our hypothesis was that there would be a linear relationship between the screw thread depth and the fixation strength of the screw. To investigate this question, we fabricated custom-made screws with the only changed variable being the thread depth and conducted a demonstration test on the pull- out strength. The purpose of this study was to clarify the relationship between the thread depth and fixation strength of metal cancellous screws for cancellous bone.

MATERIALS AND METHODS

Preparation of experimental screws A brass (C2801) rod with a diameter of 6 mm was cut into shorter rods with lengths of 50 mm using a disc grinder. Experimental screws were made from those short rods using a numerical control lathe (MTS4, Nano System Solutions, Yokohama, Japan). Most elements of the screw had fixed values: a total length of 40 mm, a screw head length and diameter of 10 mm and 6 mm, a shaft length and major diameter of 15 mm and 4.5 mm, a thread region with a length of 15 mm, a pitch of 1.6 mm, and a symmetrical thread with a thread width of 0.20 mm.

Polyurethane foam blocks (TANAC Co. Ltd., Gifu, Japan) with densities of 10 and 20 pounds per cubic foot (PCF), 0.16 and 0.32 g/cm3 respectively, were used as simulated bone. The blocks were cut to 40 × 20 × 20 mm, with 90 small blocks prepared at each density. A 20-mm-long hole parallel to the long axis was pre-drilled into the center of the bottom surface of the block using a drilling machine. For each screw, the diameter of the pre-drilled hole was the same as the screw's inner diameter.

To measure the fixation strengths of screws, a pull-out test was performed 10 times for each screw. After applying 5 N preload, the screw pull-out test was performed in the direction parallel to the screw axis at 5 mm/min as indicated by ASTM F543. The pull-out strength was defined as occurring when the force reached a peak.

The insertion torque was measured under the condition of a load less than 10N and 18 rpm in rotation speed and was recorded every 0.01 sec. The maximum value recorded during the initial four revolutions of the specimen was selected as the value.

The relationship between the true value of the thread depth and the pull-out strength or the insertion torque on each screw was analyzed using simple regression analysis. P-values less than 0.05 were considered to indicate significance.

RESULTS AND DISCUSSION

As we predicted, a linear relationship was found between the screw thread depth and the fixation strength of the screws. Additionally, this relationship was biphasic: the pull-out strength increased significantly from a thread depth of 0.1 mm to 0.4 mm and then more gradually after that. The relationship between the insertion torque and the pull-out strength also showed a similar relationship to thread depth, but it seemed to be more greatly affected by the thread depth than was the pull-out strength. Many studies have been conducted on factors related to screw fixation strength. In general, there is a consensus that screws that are thicker in diameter, greater in length, and with a higher TSF tend to have a greater screw fixation strength. Among them, TSF is a complex factor calculated as the relationship between the mean thread depth and the pitch, given by TSF= (0.5 + 0.57735 d/p), where'd is the thread depth, and p is the pitch of the screw. A deeper thread depth and a narrower pitch leads to greater screw fixation strength in the calculation. In other words, these two factors have a contradictory relationship. Therefore, the relationship between the screw fixation strength when the thread depth and screw pitch are individually changed is an important piece of information when considering the optimal screw shape.

In contrast, FEM analysis can exclude other factors deliberately and hence can isolate the effect of thread depth on fixation strength. Some previous studies have described the stress distribution of implants with different thread depths using FEM analysis. To summarize these results, FEM analyses have suggested that a screw depth of around 0.4 mm is the optimum value in terms of stress dispersion.

To accurately understand the effect of thread depth on screw fixation strength, an empirical study in which the screw depth is the only variable and other factors are kept as uniform as possible would be ideal. To our knowledge, our study is the first empirical study to investigate the effect of thread depth as a single variable. Our results were almost consistent with those of the previous literature. In other words, we confirmed that the deeper the screw depth, the greater the strength of the screw fixation, a relationship that becomes especially pronounced in the osteoporosis model. On top of that, what we newly found was a change in the linear relation after a thread depth of 0.4 mm. As mentioned above, previous literature about FEM analyses have shown that a thread depth of around 0.4 mm may be optimal, and we believe that our results are consistent with this. When loading the pull-out stress to the screw, breakage typically happens on the bone adjacent to the major diameter surface of screw.

The effect of the captured bone volume into the screw thread is theoretically small if the breakage under pull-out load happens without slipping of the thread. We believe that the increase in screw fixation strength with increasing thread depth in this situation is probably the result of stress distribution against the pull-out load.

In our study, the rate of increase in pull-out strength per 0.1 mm thread depth at thread depth 0.4 mm or more was 5.5% in the osteoporosis model (10 pcf), which was about three times that of the normal bone model (20 pcf) 1.7%. Advice et al clarified that the density of the host site was the main factor influencing the pull-out strength of the screw.

With TD0.4 as the boundary, independent of bone density. On the other hand, the insertion torque tended to increase as the thread depth increased compared to the pull-out strength. This result is consistent with previous reports and can be explained by the fact that the area of contact between the bone and the screw surface increases with the increase in thread depth, as a result, the frictional force increases.

CONCLUSION

In conclusion, the pull-out strength of 4.5-mm-diameter metal screws in a cancellous bone model was found to be biphasic, although linearly correlated with the change in screw depth in both phases. The boundary of the correlation was 0.4 mm regardless of the density of the bone model, and the effect of screw depth beyond that on the pull-out strength was small in comparison. This result is important information for future orthopedic screw design.