Biomechanical Comparison of Stiffness for Single versus Dual-Threaded Pedicle Screws

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Introduction:
Traditionally, pedicle screws have been designed with a single pitch thread. These designs are conventionally optimized for insertion within either the cortical or cancellous bone. However, screw insertion usually results in the shaft residing in both cortical and cancellous bone. A pedicle screw possessing a dual-threaded design could then potentially provide better fixation than a single-threaded design by taking advantage of both vertebral bone densities. The hypothesis for this study was that a dual-threaded pedicle screw would exhibit superior mechanical characteristics to a single-threaded design.

Materials and Methods:
A bovine calf model from T11 to L4 was employed to reduce the effects of specimen variability. For each vertebral body, a dual-threaded (DT) and single-threaded (ST) screw (Figure 1) was inserted into each pedicle in a randomized fashion. A total of 12 vertebral bodies were subjected to toggle fatigue. Toggle testing consisted of sinusoidal loading between ±340 N to 2600 cycles at 0.5 Hz. Load and displacement data were collected at 100-cycle intervals.

The linear compressive stiffness for each cycle interval was computed by performing a linear regression of load versus deflection in the elastic region of the curve during compression. The resulting slope (stiffness) for each screw type was averaged for each cycle interval between screw designs. A non-linear regression of stiffness versus cycle number was performed for each screw type. A Student’s t-test was performed between the resulting mechanical parameters as well as the initial (cycle 100) and final (cycle 2600) stiffness values for each screw type in order to elucidate if a significant decrease in stiffness was observed at the termination of the toggle test.

Results:
Both screw types resulted in a fitted curve of the form seen in Figure 2, where the Plateau is the Independent Variable (Y) value at infinite cycle number (i.e. the asymptote); K is the rate constant, expressed in reciprocal of the X axis units (Cycles⁻¹) and is related to the rate at which the stiffness value changes over the number of cycles; Half-life is in the units of the X axis and is computed as ln(2)/K and represents the point at which a 50% change in the stiffness value has occurred; and Span is the difference between Y₀ and Plateau, or the change in stiffness over the course of the toggle test.

The mean stiffness versus cycle number for each screw type is seen in Figure 3. Both curves were fit with resulting r² values in excess of 0.95. With respect to performance, the DT screw design displayed a more rapid decrease in stiffness to the plateau or asymptotic stiffness value with a rate value of (5.3±0.2)×10⁻³ Cycles⁻¹, as compared to a rate value of (2.91±0.07)×10⁻³ Cycles⁻¹ for the ST screws. In computing the respective half-life, which may be considered a mathematical indicator for clinical settling time, or a point at which the effective stiffness of the screw within the pedicle is no longer changing to an appreciable level. The DT screws (1308±337 cycles) displayed a significant reduction in cycles required to settle as compared to the ST screws (2385±583 cycles (P<0.01). (Figure 4)

Comparing the initial stiffness values to the final stiffness values computed upon the termination of the loading regimen, no statistically significant decrease in stiffness for the DT screw design was evident (P>0.23). However, a similar comparison for the ST screws yielded a significant decrease in stiffness (P<0.045). (Figure 5)

Discussion:
The DT screw design displayed an increased rate for settling by virtue of a reduced half-life value (as defined above) with respect to the traditional ST screw design. The rapid settling will ensure that localized deformations at the bone screw interface will remain small and constant, thereby aiding in the initial phases of fusion.[1] Perhaps more significantly, is that while initially the ST displayed an increased stiffness as compared to the DT, at the termination of the toggle test, the DT design resulted in a stiffness (Plateau) value of (414±3)N/mm that exceeded that of the ST screw (381±13)N/mm (P<0.01). The data suggest that a screw possessing a dual thread will settle faster to a stiffness value comparable to the initial stiffness and remain at this performance level. In contrast, an ST screw design will display reduced stiffness and slowly settle to a value that is statistically reduced compared to the initial stiffness. The performance characteristics of the respective screw designs present clinicians with a selection paradigm; decreased screw stiffness (ST) could aid in stress shielding to the anterior column, yet possibly result in loosening, as compared to a system (DT) that should retain stability in an attempt to promote osteogenic processes for fusion. Ultimately, clinical data with respect to fusion rate will provide the definitive clinical validation for the new DT design.


Figure 1. The Single-Thread (ST) and Dual-Thread (DT) screw designs with test set up for toggle fatigue.

Figure 2. For both designs, screw stiffness versus cycle number resulted in a one-phase decay curve.

Figure 3. The resultant non-linear fit for both screw designs. Both data sets resulted in r² values for the fitting in excess of 0.95.

Figure 4. The half-life (or settling) of the stiffness values occurred significantly faster with a DT as compared to ST.

Figure 5. No significant decrease in stiffness was noted for the DT screws over the application of the testing regimen. A statistically significant decrease was observed for the ST screw design.