

# Pullout Strength Variance Among Self-Tapping Screws Inserted to Different Depths

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## ABSTRACT

The cortical self-tapping screw (STS) has replaced the non-STs as an aid in fracture fixation. In a recent biomechanical investigation, Berkowitz and colleagues found that STS pullout strength increased with insertion depth up to 1 mm past the far cortex only.

In the present study, we wanted to apply a standardized protocol of assessing pullout strength to STSs of different compositions and manufacturers while eliminating the sample-size and block-variance issues that affected the previous investigation. Ninety STSs were randomly divided into 5 groups, each representing a different insertion depth. Peak force was determined with trials ending in screw pullout or failure.

A statistically significant difference in pullout strength was identified with insertion depths up to 1 mm past the far cortex. No block variance was detected. These results support the recommendation that STSs be inserted only 1 mm past the far cortex in healthy cortical bone.

Cortical screws are a well-established component of the fracture-fixation armamentarium. Historically, the non-self-tapping screw (non-STs) was used for fracture fixation, but the STS has become more popular in recent years and is now preferred. It can be inserted easier and quicker and thus can reduce operative

time and associated complications (eg, blood loss, increased risk for infection).<sup>1</sup> These benefits derive from use of a cutting flute, which allows for screw insertion without the use of a tap. Unfortunately, it has been reported that, when the flute is left in the far cortex of the bone, screw pullout strength is decreased 10% to 30%.<sup>2</sup>

Anecdotal evidence suggests that STSs should be inserted 2 mm past the far cortex to prevent the cutting flute from remaining in the far cortex.<sup>2-7</sup> The rationale is that a flute in the far cortex decreases the surface area of

**“[our] results...may [allow us to] ...advocate inserting cortical STSs only 1 mm past the far cortex in patients deemed to have healthy cortical bone.”**

screw threads contacting cortical bone.<sup>2,4-6,8</sup> This widely quoted recommendation, however, is not supported in the literature.<sup>2,4-6,8</sup> In fact, a veterinary study using synthetic and canine models demonstrated no statistically significant difference in pullout strength between completely inserted and incompletely inserted STSs.<sup>8</sup>

On the basis of findings from the veterinary study, Berkowitz and colleagues<sup>5</sup> endeavored to determine whether depth of insertion of STSs (50 Synthes 3.5-mm STSs) through the far cortex significantly affects pullout strength. Their results refuted the recommendation that STSs be inserted 2 mm past the far cortex in fracture fixation. STS pullout strength increased with insertion depth up to 1 mm past the far cortex, but there was no statistically significant increase in pullout strength among screws inserted past 1 mm. Berkowitz and colleagues maintained that this is an important finding, not only because it allows for a definitive recommendation based on statistically significant biomechanical testing, but because protruding screw tips increase the risk for damage to muscle and neurovascular structures adjacent to the far cortex of fixated bone. Their results indicate that maximal holding power is achieved once the STS tip penetrates the far cortex. The researchers surmised that the conical tip allows the screw to maintain sufficient pullout strength while piercing only the surface of the far cortex.

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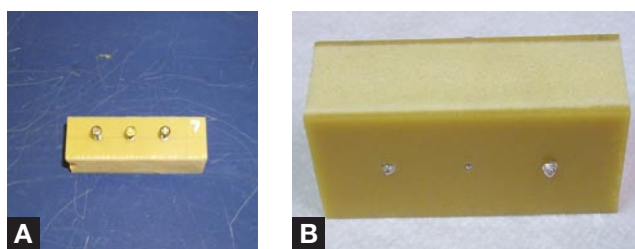
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**Figure 1.** Bone coupon of synthetic cancellous bone and E-Glass-filled epoxy sheet lamination (Pacific Research Laboratories, Vashon, Wash). (A) Screws inserted into coupon (B) Different depths past the far cortex.

The study by Berkowitz and colleagues,<sup>5</sup> however, had its limitations. First, only 50 STSs were used, so, despite the statistically significant findings, the power of the study was limited. Second, only Synthes screws were tested, so no comment can reliably be made about the other popular orthopedic systems used in fracture fixation (eg, Zimmer, Stryker Howmedica). Third, there was block variance in the bone coupons used in the pullout trials; although more trials for the groups with similar data were run to achieve significance, and Student-Newman-Keuls post priori tests were performed to account for this variance, there still may have been a deleterious effect on study results.

In the present study, we sought to determine if the findings of Berkowitz and colleagues<sup>5</sup> can be generalized to STSs made by other companies and to identify any significant variations in pullout strength among these STSs. We also sought to increase the statistical significance of those investigators' findings by increasing the power of their study and eliminating block variance.

## MATERIALS AND METHODS

Thirty Synthes stainless steel STSs (Synthes, West Chester, Pa), 30 Synthes titanium STSs, and 30 Zimmer stainless steel STSs (Zimmer, Warsaw, Ind) were inserted into synthetic bone coupons (Pacific Research Laboratories, Vashon, Wash) in a randomized fashion. All screws were 40 mm long and had a 1.25-mm pitch and 3 cutting flutes. Flute lengths were 3.9 mm (SD, 0.15 mm). Bone coupons were obtained in a single sheet from Pacific Research Laboratories and were cut to 76×25 mm. Synthetic cortical bone consisted of E-Glass-filled epoxy sheets (Pacific Research Laboratories, Vashon, Wash) with a tensile modulus of 12.4 GPa and a tensile strength of 90 MPa. Synthetic cancellous bone consisted of cellular rigid polyurethane foam with a tensile modulus of 1.2 GPa and a tensile strength of 16 MPa.

Three STSs were inserted into each bone coupon. Given St. Venant's principle (the difference between stresses caused by statically equivalent load systems is insignificant at distances greater than the largest dimension of the area over which the loads are acting), using 3 screws per coupon ensured adequate space for preventing coupon damage from a pullout trial from affecting the strength of adjacent screws.<sup>9</sup>

The 90 STSs were randomly divided into 5 insertion-depth groups of 18 screws each: 6 Synthes stainless steel, 6 Synthes titanium, and 6 Zimmer stainless steel. In group

**Table I.** Mean Pullout Strengths of Screws at Different Depths of Insertion

Insertion Depth (mm)	Pullout Strength (lb)
-1	966.9311765
0	1032.662778
1	1099.810556
2	1120.224118
3	1151.807222

**Table II.** Stainless Steel Screw Pullout Strengths in Berkowitz et al<sup>5</sup> Study and Present Study

Insertion Depth (mm)	Pullout Strength (lb)	
	Berkowitz et al <sup>5</sup>	Present Study
-1	310.80	971.74
0	352.70	1046.77
1	440.50	1147.57
2	453.38	1122.21
3	460.36	1164.74

1, screw tips were inserted 1 mm short of the far cortex; in group 2, screw tips were inserted flush with the far cortex; and, in groups 3 to 5, screw tips were inserted 1, 2, and 3 mm past the far cortex, respectively (Figure 1). Precise insertion was achieved with a Bridgeport milling machine (Hardinge, Inc., Elmira, NY), which was used to prepare the holes for insertion, and a dial indicator depth gauge (sensitive to 0.001 in), which was used to ensure accurate insertion depth.

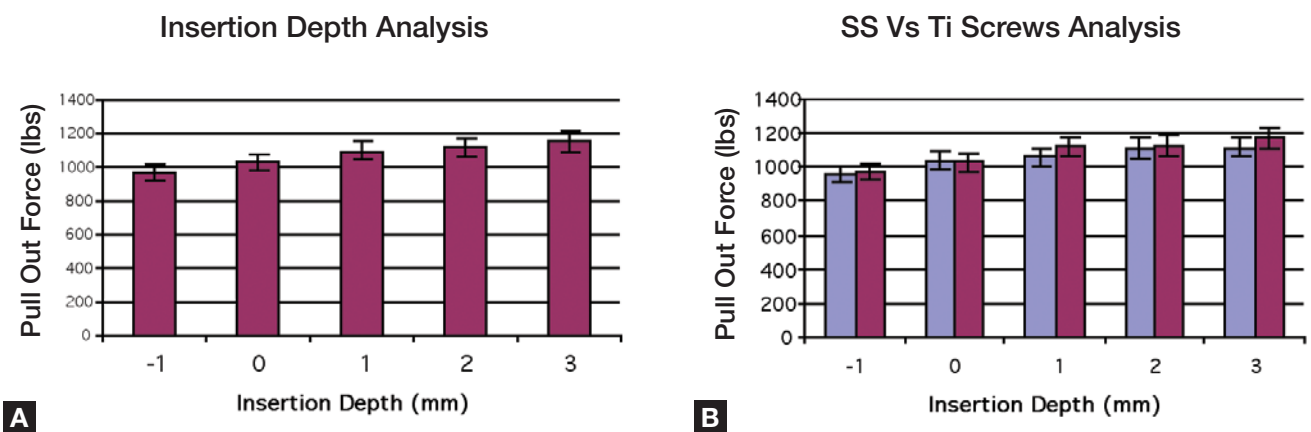
Peak force and stiffness were determined with an Instron 8511 materials testing system (Norwood, Mass). Each screw was pulled out with a fixture that slipped over the screw head. For ensuring that only axial pullout forces were applied, a universal joint was used in the load train. Testing was conducted under displacement control at a rate of 1 mm/s. Maximal load and displacement data (Figure 2) were collected at 30 Hz and stored on a personal computer.

The statistical model used in this study was a multivariate analysis of variance-balanced incomplete block design. Group and screw manufacturer were the independent variables, and peak force was the dependent variable. Statistical analysis was done with SAS software (SAS Institute, Cary, NC).

## RESULTS

All trials ended with either screw pullout or failure. Eight screws were visibly damaged in the study, with cracking and separation occurring immediately distal to the screw heads. There was no evidence of cracking or fissuring of the bone coupons that extended into adjacent screw holes. There was none of the block variance that had been detected by Berkowitz and colleagues.<sup>5</sup> Furthermore, the number of trials that had to be performed did not vary—which we attributed to the fact that all bone coupons were cut from a single sheet.

Initially, peak force values were determined for the 5 insertion-depth groups without differentiating between screw composition or manufacturer. Table I lists the results for the 5 groups: 966.93 pounds for group 1; 1032.66



**Figure 2.** Graphs summarizing mean pullout strengths (A) at different depths of insertion and (B) for the stainless steel and titanium screws at different depths of insertion.

pounds for group 2; 1099.81 pounds for group 3; 1120.22 pounds for group 4; and 1151.81 pounds for group 5. Groups 1 and 2 differed by 6.7%, groups 2 and 3 by 6.5%, groups 3 and 4 by 1.8%, and groups 4 and 5 by 2.8%. There was a statistically significant difference in pullout strengths between groups 1 and 2 and between groups 2 and 3 ( $P < .0001$ ) but not among groups 3 to 5. Additional statistical analysis demonstrated a power of 0.93.

The initial pattern of pullout strength variance held even when screw composition and manufacturer were controlled for. Results for the Synthes titanium screws were 956.94 pounds for group 1; 1039.88 pounds for group 2; 1064.26 pounds for group 3; 1110.72 pounds for group 4; and 1117.33 pounds for group 5. Again, the difference between groups 1 and 2 and the difference between groups 2 and 3 were the only statistically significant ones.

Mean pullout strengths for the Synthes stainless steel screws were 971.74 pounds for group 1; 1046.77 pounds for group 2; 1147.57 pounds for group 3; 1122.21 pounds for group 4; and 1164.74 pounds for group 5. In this trial, statistical significance was reached only in the comparisons between groups 1 and 2 and groups 2 and 3.

Pullout strengths for the Zimmer stainless steel screws followed a similar pattern: 970.44 pounds for group 1; 1011.34 pounds for group 2; 1101.49 pounds for group 3; 1126.15 pounds for group 4; and 1173.35 pounds for group 5. As in the other trials, the only statistically significant differences were found between groups 1 and 2 and groups 2 and 3.

In the comparisons of the pullout strengths of the Synthes stainless steel screws and the Synthes titanium screws, no statistical significance was found at any insertion depth. Likewise, there was no statistically significant difference between the pullout strengths of the 2 types of stainless steel screws (Synthes and Zimmer) inserted to the same depth.

## DISCUSSION

Our goal in this study was to answer several questions about the biomechanical properties of Synthes stainless steel, Synthes titanium, and Zimmer stainless steel cortical STSs. We sought to replicate the results reported by Berkowitz and

colleagues<sup>5</sup> while eliminating the block-variance and sample-size issues that affected their investigation. We also hoped to determine whether their findings could be applied to STSs of different compositions and manufacturers. The synthetic bone blocks used in our study have been accepted as a suitable model for biomechanical studies.<sup>10</sup>

Our results clearly agree with those of Berkowitz and colleagues,<sup>5</sup> but there are some differences. The pattern of results for all screws in our study—statistically significant differences in pullout strength among screws inserted 1 mm short of the far cortex, screws inserted flush with the far cortex, and screws inserted 1 mm past the far cortex—is almost identical to the pattern they found. There was no statistically significant difference in pullout strength for screws inserted 2 or 3 mm past the far cortex.

Our pullout strengths, however, are consistently higher than those reported by Berkowitz and colleagues.<sup>5</sup> In their study, for example, pullout strengths were 310.8 pounds for Synthes stainless steel screw tips inserted 1 mm short of the far cortex, 352.7 pounds for tips inserted flush with the far cortex, and 440.5 pounds for tips inserted 1 mm past the far cortex; in comparison, values for our Synthes stainless steel screws were almost 3 times higher (Table II). This significant difference can be explained by the presumed differences in bone coupon composition in their study. Although their findings adequately demonstrated the trend in STS pullout strength based on insertion depth, the actual pullout strengths in their study appear to be significantly underestimated.

The better quality of our synthetic coupon, representative of younger, healthier bone, can account for the damage and failure identified in some of our screws. These bone blocks, reflecting the qualities of normal cortical bone in the young and active, also limit the scope of this research, as the findings reported here can be safely applied only to healthy cortical bone and cannot be used in making screw-depth recommendations for osteoporotic bone, osteopenic bone, or bone weakened by a metabolic or malignant process.

Our study results confirmed the trend reported by Berkowitz and colleagues<sup>5</sup> and seem to indicate that holding power is maximized once the STS tip penetrates the

far cortex of healthy bone. These results had marked statistical significance ( $P<.0001$ ) and increased power (0.93). Furthermore, we avoided the block variance that Berkowitz and colleagues encountered. Therefore, our results provide evidence against the anecdote-based suggestion that STSs be inserted 2 mm past the far cortex.<sup>2</sup>

We also determined that the principle of maximizing power merely by penetrating the far cortex could be applied to all cortical STSs, regardless of screw composition or manufacturer. Although the Synthes titanium screws predictably demonstrated lower mean pullout strength in comparison with the Synthes stainless steel screws inserted to the same depth, this finding was not statistically significant.

Given the results of the present study, we may be able to discount the current recommendations and instead advocate inserting cortical STSs only 1 mm past the far cortex in patients deemed to have healthy cortical bone. Such a change is particularly relevant because protruding screw tips pose an increased risk to soft tissue and neurovascular structures adjacent to fractured bone.

### AUTHORS' DISCLOSURE STATEMENT

The authors report no actual or potential conflict of interest in relation to this article.

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