Original Article

Pitch and Longitudinal Fluting Effects on the Primary Stability of Miniscrew Implants

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ABSTRACT

Objective: To test the hypotheses that pitch and fluting have no effect on the primary stability of miniscrew implants (MSIs).

Materials and Methods: Maximum placement torque and pullout strength of experimental MSIs were compared with those of control MSIs with the use of synthetic and cadaver bone. MSIs with 1.00 mm pitch were compared with those with 1.25 mm and 0.75 mm pitch; MSIs with three longitudinal flutes were compared with the same MSIs without flutes. A total of 60 MSIs (15 of each design) were evaluated with synthetic bone; a split-mouth cadaver model was used to compare the three experimental designs against the 1 mm control MSIs (total of 90 MSIs).

Results: The synthetic bone model showed higher placement torque and pullout strength for the 0.75 pitch than for the 1.0 mm and 1.25 mm pitch MSIs, but differences were significant ($P <$ .05) only for pullout strength. The cadaver model showed no significant differences in placement torque or pullout strength associated with pitch. Both synthetic and cadaver bone models showed that MSIs with flutes had significantly ($P <$ .05) higher placement torque and pullout strength. Spearman correlations between placement torque and pullout strength were statistically significant for both synthetic ($r =$ .504) and cadaver ($r =$ .502) bone.

Conclusion: Within limits, decreasing MSI pitch increases pullout strength, and fluting increases both placement torque and pullout strength. (*Angle Orthod.* 2009;79:1156–1161.)

KEY WORDS: Miniscrew implants; Pitch, Fluting; Pullout strength; Insertion torque

INTRODUCTION

The use of teeth for orthodontic anchorage can result in unwanted tooth movement and a compromised treatment result. Extraoral devices are less than ideal because they are dependent on patient compliance and are outside of the control of the practitioner. Although miniscrew implants (MSIs) offer solutions to both of these problems,[1] the specific design characteristics that might enhance primary stability are not fully understood.

Insertion torque and pullout tests typically are used to analyze a screw's geometry as a function of its primary stability.[2–6] Both tests provide anchorage estimates for immediately loaded MSIs.[7] Peak insertion torque has been shown to be a significant factor in determining the holding power of screw-type implants.[3–6] Pullout tests are commonly used to measure primary stability in orthopedics, orthodontics, neurosurgery, and maxillofacial surgery.[7] Pullout tests directed vertically, with forces parallel to the long axis of the screw, typically are used to evaluate the design of a screw-type implant.[8–9]

Our understanding of MSI design characteristics comes primarily from the orthopedic and prosthetic literature. Longer screws exhibit greater pullout strength than shorter screws,[10] and screws with greater diameter provide greater resistance to pullout than do their

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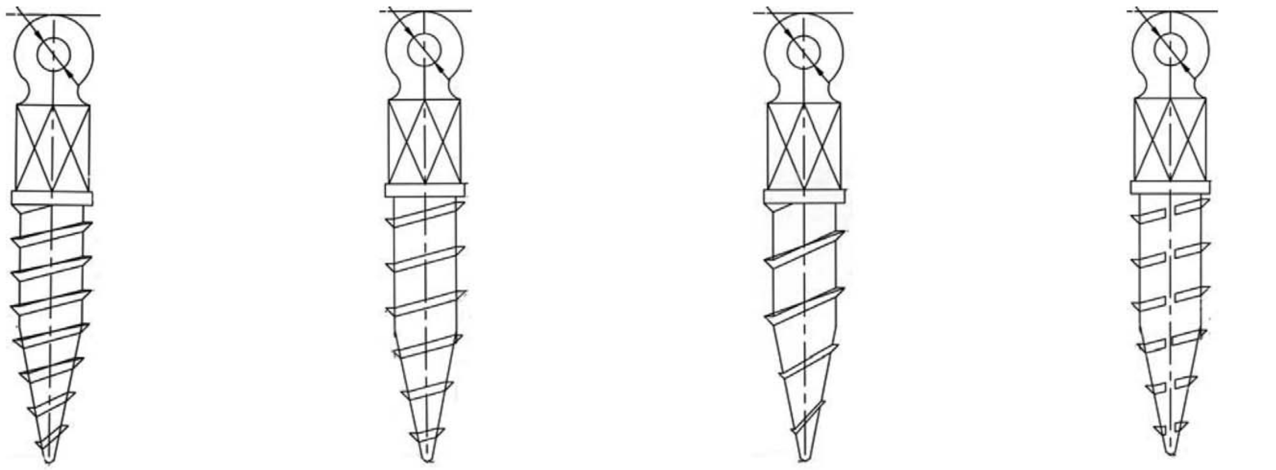

Figure 1. (A) 1.0 mm pitch control miniscrew implant (MSI). (B) 0.75 mm pitch experimental MSI. (C) 1.25 mm pitch experimental MSI. (D) Fluted experimental MSI.

counterparts with smaller diameters.[11–13] Screw-type implants with greater thread depth have greater purchase strength in porous materials and thus higher primary stability.[11,14,15] It has also been shown that an asymmetrical thread design, with a 45 degree leading and a 90 degree trailing angle, facilitates insertion while making removal more difficult.[2]

Pitch and fluting are design characteristics of MSIs that remain to be fully understood. Flutes are recessed areas in the screw's cross-sectional area that carry bone chips away from the cutting edge as the screw rotates. Decreasing the surface area of an MSI by increasing the pitch or adding flutes should, theoretically, decrease friction and placement torque. Pitch has been shown to be negatively related to pullout strength[11,14]; decreased pitch is thought to increase the screw purchase strength in porous materials.[14] However, MSIs advance farther per turn as pitch increases, which might be expected to create higher torque levels.[16] Decreased placement torque and cortical damage occur as the number and length of flutes are increased.[17] This is thought to be due to increased clearance of bone chips, which tend to accumulate around the threads and provide resistance.[15,17,18] However, bone chip clearance is also dependent on adequate flute dimensions. The presence of flutes has been reported to both decrease[17,19,20] and increase[21,22] pullout strength. Fluted screws should exhibit decreased resistance to pullout during primary stability testing because they are thought to have less holding power than fully threaded scews.[19,23]

The purpose of this in vitro study was to evaluate the effects that pitch and fluting have on primary stability of miniscrew implants. This experiment is novel because it isolates one design characteristic while holding all other characteristics constant.

MATERIALS AND METHODS

MSI Designs

Control design. Control MSIs were made of surgical grade titanium; they were 6 mm long, with major and minor diameters of 1.8 mm and 1.6 mm, respectively (Figure 1A). The thread was a 90 degree asymmetrical buttress design with a 1.0 mm pitch. The apical 3 mm of the MSI was tapered; it was self-drilling and self-tapping. Because it did not have a cutting flute at the apex that cut or tapped the bone, it was not thread cutting.

Experimental designs. To evaluate the effects of pitch, control MSIs with 1.0 mm pitch were compared with 0.75 mm and 1.25 mm pitch MSIs (Figure 1B,C). To evaluate the effects of fluting, three longitudinal flutes that extended the full length of the threaded portion were added to the control MSI design (Figure 1D). The depth of each flute extended through the threads to the core; each flute was 0.225 mm wide. The surfaces of the flutes were cutting to facilitate placement and removal.

TESTING METHODS

Both synthetic and cadaver bone models were used to evaluate the effects of pitch and fluting. Although neither of these models represents living bone, they do mimic bone and make it possible to standardize the test situation.

Table 1. Effects of MSI Pitch on Placement Torque and Pullout Strength in the Synthetic Bone Model

	0.75 mm		1.0 mm		1.25 mm		
	50th	25th, 75th	50th	25th, 75th	50th	25th, 75th	Diff Prob
Placement torque, Ncm	9.05	8.00, 10.40	8.45	7.60, 9.25	8.15	7.30, 9.15	.275
Pullout, N	22.16	18.20, 27.47	10.80	5.41, 14.80	12.70	7.97, 25.33	.001

Synthetic Bone Model

A synthetic polyurethane cancellous bone model (Sawbones, Vashon, Wash) was used to ensure uniformity when insertion torque and pullout strength were evaluated. Synthetic bone has been used commonly to evaluate the design characteristics of screws.[2,11,14] The synthetic bone had a density of 15 pounds per cubic foot, a compressive strength of 5.2 MPa, a tensile strength of 3.7 MPa, a shear strength of 3.2 MPa, and moduli of 156 MPa, 173 MPa, and 42 MPa, respectively. Square blocks (10 mm3) of synthetic bone were cut from a larger block for testing. Fifteen control MSIs and 45 experimental MSIs (15 for each experimental design) were evaluated in the synthetic bone.

Cadaver Bone Model

Partially dentate male cadavers between 68 and 91 years of age with formalin perfusion were used. Formalin perfusion has been shown to more closely retain the mechanical properties of fresh bone than of bone fixed in formalin, whether or not it had been washed out before testing.[24] All subjects were free of overt osseous pathology. The soft tissues were dissected and the mandibles were sectioned at the symphysis to facilitate testing. A split-mouth design (15 MSIs per side) was used to evaluate the effects of pitch and fluting, with a control MSI randomly assigned to one side and an experimental MSI placed in the same location on the opposite side. Placement sites were restricted to the alveolus and were posterior to the external oblique ridge.

MECHANICAL TESTING

Placement Torque

Measurements of placement torque were obtained with the Mecmesin (Mecmesin Ltd, West Sussex, UK) static torque screwdriver. All miniscrews were hand-placed with intermittent rotation into specimens secured in a custom-made device. The screwdriver was braced and maintained in the same position throughout insertion. All MSIs were fit into the torque screwdriver with an custom adapter. Overall maximum insertion torque was recorded in Ncm.

Pullout Strength

For pullout testing, specimens were mounted on an Instron (Instron Corp, Canton, Mass) Machine Model 1011 with the use of custom holding devices (one for synthetic and one for cadaver bone). These holding devices allowed flexure of the bone by leaving an 8 mm^2 cylindrical area surrounding the unsupported MSI. Forces were applied to the miniscrews by threading two 0.012 inch stainless steel ligatures through the MSI head and securing them to the Instron machine. A vertical force of 10 mm/min, oriented parallel to the long axis, was applied until failure occurred. Load displacement data were recorded, and the peak load at failure was reported in Newtons (N).

Statistical Analysis

Skewness and kurtosis statistics showed significant ($P < .05$) departures from normality for a number of distributions. On that basis, medians (50th percentile) and interquartile ranges (25th, 75th percentiles) were used for descriptive purposes. Pitch was evaluated first with the use of the Kruskal-Wallis test followed by pairwise comparison with a Mann-Whitney test. The effect of fluting was evaluated with a Mann-Whitney test. The relationship between insertion torque and pullout strength was assessed by means of Spearman rank order correlation.

RESULTS

Synthetic Bone Model

Pitch. Placement torque with 0.75 mm pitch was higher than placement torque with 1.0 mm and 1.25 mm pitch MSIs, but the differences were not statistically significant (Table 1). The maximum pullout force at failure was significantly different ($P = .001$) between the three groups of MSIs. Post hoc testing showed that it was significantly higher for 0.75 mm pitch MSIs than for MSIs with a 1.0 mm pitch ($P < .001$). Differences in maximum pullout between the 1.0 mm and 1.25 mm pitch MSIs were not statistically significant. Pullout of the 0.75 mm pitch MSIs was also statistically greater ($P = .015$) than pullout with a 1.25 mm pitch.

Fluting. Placement torque (Table 2) and pullout strength were significantly greater ($P < .001$) for MSIs

Table 2. Effect of MSI Fluting on Placement Torque and Pullout Strength in the Synthetic Bone Model

	Fluted		Control		Diff
	50th	25th, 75th	50th	25th, 75th	Prob
Placement torque, Ncm	9.70	9.40, 12.2	8.45	7.60, 9.25	<.001
Pullout strength, N	56.19	48.54, 58.83	10.80	5.41, 14.80	<.001

with flutes than for control MSIs in the synthetic bone model.

Cadaver Bone Model

Pitch. No significant differences in placement torque or pullout strength were found between 0.75 mm and 1.0 mm pitch MSIs (Table 3). No significant differences in placement torque or pullout strength were observed between 1.0 mm and 1.25 mm pitch MSIs (Table 4).

Fluting. Placement torque of fluted MSIs was significantly greater ($P < .001$) than that of control MSIs (Table 5). Pullout strength was also significantly greater ($P = .027$) for fluted MSIs than for control MSIs. Placement torque and pullout strength were significantly correlated in both synthetic ($r = .504$; $P < .001$) and cadaver ($r = .502$; $P < .001$) bone models.

DISCUSSION

MSIs with 0.75 mm pitch provided greater primary stability than was provided by 1.0 mm pitch MSIs. The synthetic model showed that the pullout resistance of 0.75 mm pitch MSIs was significantly greater than in those with a pitch of 1.0 mm. Although not statistically significant, the 0.75 mm MSIs also had higher placement torque than the 1.0 mm MSIs. A 0.75 mm pitch provides a greater surface area than the 1.0 mm pitch, which increases torque as the result of increased friction at the bone-to-screw interface.[9] Although not statistically significant, the cadaver model displayed similar tendencies. These findings are consistent with those of studies showing significant increases in pullout resistance with decreasing pitch.[11,14] A decrease in MSI pitch is thought to increase resistance to pullout because of an increase in MSI purchase strength of porous materials.[14]

Table 3. Differences in Torque and Pullout Strength Between 0.75 mm and 1.0 mm MSIs in the Cadaver Bone Model

	0.75 mm		1.0 mm		Diff
	50th	25th, 75th	50th	25th, 75th	Prob
Placement torque, Ncm	15.2	12.6, 16.5	13.6	10.8, 16.2	.88
Pullout strength, N	68.45	61.98, 77.18	63.94	41.48, 79.63	.363

Table 4. Differences in Torque and Pullout Strength Between 1.0 mm and 1.25 mm MSIs in the Cadaver Bone Model

	1.0 mm		1.25 mm		Diff
	50th	25th, 75th	50th	25th, 75th	Prob
Placement torque, Ncm	11.45	10.7, 12.45	12.6	11.45, 14.3	.300
Pullout strength, N	51.29	38.44, 69.73	51.29	41.48, 74.43	.609

Placement torque and pullout strength showed no significant differences between 1.25 mm and 1.0 mm pitch MSIs. Expected decreases in torque and pullout strength with the 1.25 mm pitch MSIs might have been compensated for by higher compressive torque. MSIs are designed to convert torque into compressive force between the screw and the bone. The inclined plane of the MSI thread produces an axial force as it is inserted,[16] causing shear stresses to develop.[25] MSI pitch determines how much the screw advances with each turn,[16] with greater amounts of advancement creating higher axial forces. A pitch of 1.25 mm advances the MSI farther per turn than does a 1.0 mm pitch; it also creates greater axial stress (or compression) and torque. The thickness of the bone should also be considered because primary stability may be compromised when an MSI with a pitch of 1.25 mm is inserted into cortical bone that is only 1 to 2 mm thick, because of the limited space available for thread engagement.[26]

Cutting flutes had a significant effect on both placement torque and pullout strength of the miniscrew implants. The higher placement torque found with the fluted MSIs could have been due to bone chips that accumulated around the threads of the fluted MSIs, providing greater friction and resistance to insertion.[15,17,18] Because the MSIs were inserted with intermittent rotation, it is also possible that the bone could rebound into the flutes during rotational pauses,[27] making it necessary to exert more force to turn the MSI.[21,27] Increased pullout resistance with fluted MSIs can be explained by the engineering principal of matched deformations. This principal states that components must be designed to deform similarly under a given load to avoid uneven distribution of load and

Table 5. Differences in Torque and Pullout Strength Between MSIs With Flutes and Control MSIs Without Flutes in the Cadaver Bone Model

	Fluted		Control		Diff
	50th	25th, 75th	50th	25th, 75th	Prob
Placement torque, Ncm	19.1	17.6, 23.2	8.7	7.9, 11.8	.001
Pullout strength, N	82.57	52.76, 104.34	50.80	39.13, 71.98	.027

high stress concentration.[28] The flutes created breaks in the titanium threads, making them more flexible and decreasing the stiffness of the MSI, so as to more closely match the bone. Similar load deformations of two interacting systems even out the load distribution and increase the strength of the system.

Moderate positive correlations were found between placement torque and pullout strength in both synthetic and cadaver bone models, which supports the orthopedic literature.[5,17] Peak insertion torque has been shown to be a significant factor in predicting the holding strength of screw-type implants.[3–6] Ryken et al[4] have suggested that up to 76% of the variability in pullout strength can be attributed to placement torque. This relationship suggests that increased torque reflects tighter bone-to-implant contact and increased primary stability.

Two different bone models were chosen for testing purposes only; more specifically, they were chosen to simulate rather than emulate fresh or living bone. The synthetic bone used had different material properties than cortical bone. It was chosen because synthetic bone provides consistent material properties and has been commonly used to evaluate and compare design characteristics of screws.[2,11,14] Although formalin perfusion alters the properties of cadaver bone, it has been shown to more closely retain the mechanical properties of fresh bone than of bone fixed in formalin.[24] The consistency of results observed for the two bone models validates their use. Although torque and pullout strengths observed in the present study should not be anticipated for fresh bone, the relative differences associated with pitch and fluting might be expected to apply.

First, this study showed a high coefficient of variability for insertion torque and pullout strength, especially for the cadaver models. This could be explained in part by variability in the design of the MSI heads. Some of the MSIs were slightly more difficult to remove from the driver than others, which could increase variability by altering the integrity of surrounding bone. Second, the use of human cadaver models adds variation to testing because differences in density and cortical thickness are seen not only among the samples, but also within each specimen.[11,29,30] Finally, even though all tests were performed in a standardized manner by one operator with calibrated instruments, measurement variability was obviously introduced based on results from the synthetic bone model. Additional studies are needed to confirm these results.

CONCLUSIONS

- Pullout strength significantly increases as pitch decreases from 1.0 mm to 0.75 mm.
- No significant difference in placement torque or pullout strength has been noted between MSIs with a 1.0 mm and a 1.25 mm pitch.
- MSIs with flutes have significantly higher placement torque and pullout strength than MSIs without flutes.
- A positive correlation between placement torque and pullout strength has been noted.

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