Effects of Pilot Hole Size and Bone Density on Miniscrew Implants' Stability

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ABSTRACT

Problem: How does pilot hole size and bone density affect the primary stability of miniscrew implants (MSIs)?

Methods: Using 120 MSIs divided equally into six groups, this 2×3 factorial design evaluated the effects of synthetic bone density (0.64 g/cc vs 0.8 g/cc cortices) and pilot hole size (no pilot hole, 1.0 mm pilot hole, and 1.4 mm pilot hole) on maximum insertion torque and pullout strength. The maximum placement torque was measured as the last thread of the MSIs was inserted. The pullout strength test applied a vertical force at 10 mm/min until failure.

Results: The insertion torque and pullout strength values were significantly ($p \leq .05$) greater for the MSIs placed in high-density than in low-density cortical bone. The insertion torque and pullout strength decreased as pilot hole size increased, with significant ($p \leq .05$) differences between all three subgroups. Insertion torque and pullout strength were significantly intercorrelated for all subgroupings, with stronger correlations in denser bone having smaller or no pilot holes.

Conclusion: Depending on bone density, pilot holes of limited size can be used to optimize primary stability by decreasing insertion torque while maintaining the pullout strength of bone.

KEY WORDS: bone density, miniscrew implants, pilot hole size

INTRODUCTION

Orthodontic anchorage has been defined as "resistance to unwanted tooth movement."[1] Dental implants require little or no compliance and provide absolute anchorage,[2,3] but their use is limited because of their large size, the two-stage surgeries required, their direction of force application, the risks of damaging anatomic structures, and difficulties maintaining proper hygiene. Midpalatal implants, which partially address the space limitations, are restricted to the maxilla. Miniscrew implants (MSIs) provide a compliance-free approach for overcoming many of these shortcomings; they also allow practitioners to have control over anchorage in situations where traditional methods of maintaining anchorage are impossible.[4] MSIs are increasingly being used because of their affordability, ease of placement and removal, ability to provide absolute anchorage, and placement versatility, allowing them to be placed in many locations including between roots of teeth.[5]

While MSIs offer many advantages, failures because of the host, the surgical technique, or the management of MSIs during treatment limit their usefulness. Park and colleagues[5] reported an overall success rate of 91.6% and related failures to miniscrew mobility, placement in the mandible, and peri-implant gingival inflammation. Greater MSI failures in the mandible may be because of more drilling required for denser bone, leading to overheating and bone necrosis.[6,7] Motoyoshi and colleagues,[8] who had a clinical success rate of 85.5%, suggested that failures were because of the lack of proper initial stability; for stability, they recommend insertion torques between 5 Ncm and 10 Ncm. High insertion torques could have created excess hoop stresses around the screw threads and caused ischemia and necrosis in the adjacent bone.[9] Cheng and colleagues,[4] who reported a success rate of 89%, found greater failure rates for implants placed in the posterior, more dense, portion of the

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mandible. They recommend using a larger pilot hole or even pretapping the bone to minimize trauma and increase the success rate.

In addition to the potential problems associated with stability, thick cortical bone can also cause screws to fracture.[10] Ellis and Laskin[11] suggested that surgical screws fracture when they are excessively stressed in tension or torsion. Chen and colleagues[12] recommended using a pilot hole in dense bone to prevent the fracture of self-drilling MSIs and to avoid failure from stripping of bone. Pilot holes also act as a guide and decrease the possibility of overdrilling through dense bone.

While various benefits of pilot holes have been suggested,[8,11,13] the effects of altering pilot hole sizes on primary stability of MSIs remain unclear. In particular, there are no studies evaluating the interaction between pilot hole size and bone density, an association that must be understood in order to individualize the appropriate pilot hole diameter. The ideal pilot hole size should provide the greatest decrease in insertion torque without compromising primary stability. This requires assessments of both insertion torque and pullout strength, qualities that have not been simultaneously considered in previous studies evaluating the effects of pilot hole size.

The purpose of this project was to determine how pilot holes and bone density affect miniscrew stability. The null hypotheses are the following:

1. Pilot hole size has no effect on insertion torque or pullout strength.
2. Bone density has no effect on insertion torque or pullout strength.

MATERIALS AND METHODS

The MSIs used for this study were the Absoanchors from Dentos© (Daegu, South Korea). The MSIs were 6 mm long, with an external diameter of 1.6 mm and an internal diameter of 0.9 mm. One hundred twenty MSIs were divided into six groups of 20 each. The six groups evaluated the effects of three pilot hole sizes and two synthetic bone densities.

Synthetic Bone

The MSIs were tested using synthetic Sawbones® (Pacific Research Laboratories, Inc., Vashon, WA, USA), which had a cancellous bone density of 0.48 g/cc (30 pcf). Two different cortical bone densities were evaluated, 0.8 g/cc (50 pcf) and 0.64 g/cc (40 pcf). The cortical bone was 2 mm thick and fixed to the cancellous bone with 40 pcf rigid polyurethane foam. The bone densities selected for this study were chosen to represent the human mandible, which has been reported to be 0.664 g/cc.[14] Synthetic bone has been shown to be a good substitute for real bone.[15] Synthetic bone, which is commonly used when evaluating implants and screws, makes it possible to control the variability of bone properties that could affect the performance of the screw's stability.[13,16]

The synthetic bone was cut into 12 mm cubes, providing at least 10 mm of bone surrounding the MSI. A customized base was fabricated to hold and prevent movements of the bone cubes. The specimens requiring pilot holes were placed into the base and secured onto the platform of a drill press. The platform was raised to fabricate the pilot holes.

Pilot Hole

There were three pilot hole preparations, one without a pilot hole, one with a 1 mm pilot hole diameter, and one with a 1.4 mm pilot hole diameter. The 1 mm–diameter pilot hole was chosen because it is the size recommended for clinical applications by the MSI manufacturer. The 1.4 mm diameter was chosen because it is approximately 87.5% of the screw's external diameter, which has been shown to be the largest pilot hole able to provide adequate stability.[16] Based on the 0.7 mm difference between the screws' external and internal diameters, the MSI thread should be engaged into 0.7 mm, 0.6 mm, and 0.2 mm of bone with no pilot hole, a 1 mm pilot hole, and a 1.4 mm pilot hole, respectively.

The pilot holes were fabricated by a drill press with a zero-sized chuck that could accommodate various drill bits. The drill press made holes that were consistently the same size and in the same axial direction. The pilot holes were 2 mm deep, extending through the cortical bone layer. The two burs used (1.0 mm and 1.4 mm in diameter) had stops placed on them so that they could only drill 2 mm deep.

Miniscrew Insertion

After the bone was placed into the base, a guide for the MSI driver was positioned and secured over the base. The guide allowed the MSI to be placed in one axial direction and prevented any wobbling during insertion. Each MSI was inserted manually with the hand driver until one thread (360°) remained exposed above the level of the cortical bone. The hand driver was then

TABLE 1 Mean Insertion Torque (IT) and Pullout Strength (POS) of Miniscrew Implants

		No Pilot Hole		1 mm Pilot Hole		1.4 mm Pilot Hole	
Density	Variable	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Low	IT (Ncm)	8.39	0.78	6.01	1.25	4.86	1.64
Low	POS (kg)	25.90	1.38	23.28	1.65	16.97	1.74
High	IT	13.09	0.87	8.90	0.83	5.88	1.06
High	POS	34.99	3.78	32.72	1.82	22.75	1.61

replaced by the Mecmesin Advanced Force and Torque Indicator (Mecmesin Ltd., West Sussex, UK), which was secured and used to measure maximum torque, while the MSI was inserted until one-half thread (180°) remained exposed. The MSIs were not entirely inserted to prevent countersink friction, which is produced when the head of the screw contacts and compresses the bone surface and biases peak insertion torque measurements.[13,17]

Pullout Strength

After measuring the insertion torque for all six groups, the base holding the bone cube was transferred to an Instron Machine Model 1011 (Instron Corp., Canton, MA, USA) and secured. The base was custom designed to fit the Instron Machine. A lid secured the synthetic bone cube to the base during pullout testing. Pullout was performed by attaching an adapter that was custom made to fit the MSI head. The adapter was tightened over the head to provide a firm hold on the MSI and attached to the Instron using a 0.040 in. stainless steel wire. A vertical force of 10 mm/min was applied and oriented parallel to the long axis of the miniscrew until failure occurred. Peak load at failure was recorded in kilograms (kg). The tensile forces needed to pull a screw out determine its pullout strength.[18]

RESULTS

Two-way analyses of variance showed a significant interaction between pilot hole size and bone density, making it necessary to evaluate the effects separately.

Pilot Holes

Low-density bone showed significant ($p < .001$) differences in insertion torque because of pilot hole size (Table 1, see Figure 1). Post hoc tests showed that insertion torque was significantly higher for the MSIs placed without pilot holes than for MSIs placed with pilot holes (Table 2); the difference between the 1.0 mm and 1.4 mm–diameter pilot holes was also statistically significant ($p = .018$). The high-density synthetic bone without pilot holes also showed significantly higher ($p < .001$) insertion torque than the bone with 1.0 mm and 1.4 mm pilot holes.

There also were significant differences ($p < .001$) in pullout strength associated with pilot holes (Figure 2). Pullout strength in low-density bone was significantly higher ($p < .001$) for the MSIs placed without pilot holes than for screws placed with pilot holes (see Table 2). The difference in pullout strength between the 1.0 mm and 1.4 mm–diameter pilot holes was also statistically significant in both high- and low-density bone.

Density

Regardless of whether or not pilot holes were used, higher density synthetic bone produced significantly greater ($p < .001$) insertion torque and pullout strength than lower density bone (Table 3). Differences in insertion torque between low- and high-density bone were

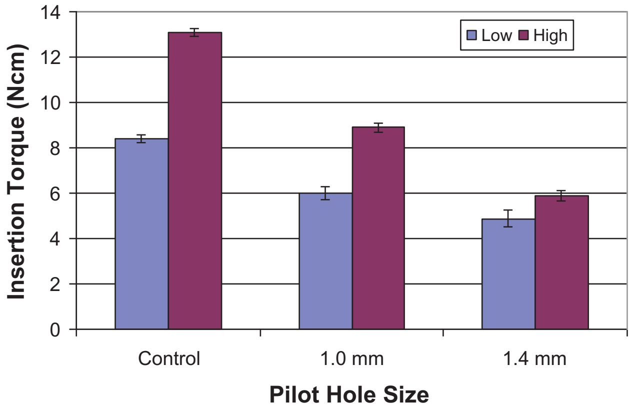

Figure 1 Mean insertion torque of 0 mm (control), 1.0 mm, and 1.4 mm–diameter pilot holes in low- and high-density synthetic bone with standard error bars.

TABLE 2 *F* Values, Probabilities, and Mean Group Differences of Insertion Torque (IT) and Pullout Strength (POS) Based on Pilot Hole Sizes

		Group Comparisons		Post Hoc Test Difference (Mean Difference)		
Density	Variable	*F*	Probability	0 versus 1	0 versus 1.4	1 versus 1.4
Low	IT	39.99	<.001	2.38*	3.53*	1.15*
Low	POS	164.84	<.001	2.63*	8.93*	6.30*
High	IT	307.81	<.001	4.20*	7.22*	3.02*
High	POS	125.82	<.001	2.27*	12.24*	9.96*

*$p < .05$.

greater without pilot holes (4.7 Ncm) than with 1.0 mm pilot holes (2.9 Ncm), which in turn were larger than the differences for the 1.4 mm pilot holes (1.0 Ncm). Differences in pullout strength between the higher and lower density bone were similar for no pilot holes (9.1 kg) and 1.0 mm pilot holes (9.4 kg), both of which were substantially higher than pullout strength with the 1.4 mm pilot holes (5.8 kg).

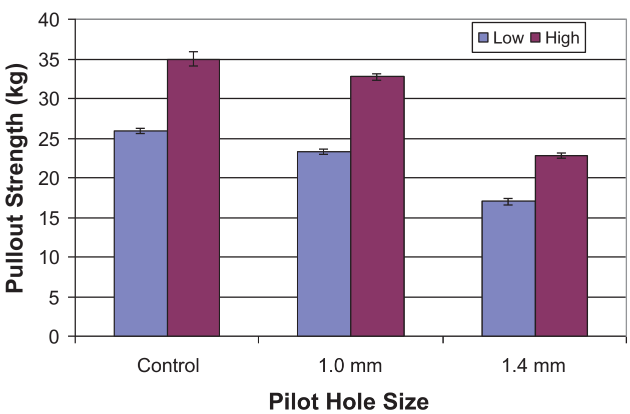

Figure 2 Mean pullout strength of 0 mm (control), 1.0 mm, and 1.4 mm–diameter pilot hole in low- and high-density synthetic bone with standard error bars.

Intercorrelations

Insertion torque and pullout strength were significantly correlated in bone without pilot holes ($r = 0.755$; $p < .001$) and in bone with 1.0 mm pilot holes ($r = 0.733$; $p < .001$). A significant but substantially lower correlation ($r = 0.331$; $p = .037$) was observed with 1.4 mm pilot holes.

Independent of pilot hole size, there was also a significant correlation ($r = 0.626$; $p < .001$) between insertion torque and pullout strength when MSIs were placed in bone of lower density. Higher density bone showed a higher correlation ($r = 0.755$; $p < .001$) between the insertion torque and the pullout strength of MSIs.

Relative Variability

The coefficients of variation showed that there was greater variation for insertion torque than for pullout strength (Table 4). With the exception of insertion torque without a pilot hole, there was greater variability in the less dense bone. Finally, pilot holes showed greater variability than no pilot holes, and 1.4 mm holes produced greater variability than 1.0 mm pilot holes.

TABLE 3 Differences in Insertion Torque (IT) and Pullout Strength (POS) between Low- and High-Density Synthetic Bone for Each Pilot Hole Size

		Group Comparisons			
Pilot Hole	Variable	*t*	Degrees of Freedom	*p* Value	Mean Difference
0	IT	−18.0	37.6	<.001	−4.7
0	POS	−10.1	24.0	<.001	−9.1
1	IT	−8.6	33.1	<.001	−2.9
1	POS	−17.2	37.6	<.001	−9.4
1.4	IT	−2.3	32.4	.026	−1.0
1.4	POS	−10.9	37.8	<.001	−5.8

TABLE 4 Coefficients of Variation Providing Percent Variability for Insertion Torque (IT) and Pullout Strength (POS) Based on Bone Density and Pilot Hole Size

Density	Variable	Control	1 mm	1.4 mm
Low	IT	9.30	20.77	33.79
Low	POS	5.33	7.09	10.27
High	IT	6.64	9.35	17.96
High	POS	10.81	5.56	7.08

DISCUSSION

There were statistically significant decreases in insertion torque when pilot holes were used and enlarged. Differences in insertion torque were relatively greater between no pilot holes and 1.0 mm pilot holes than between 1.0 mm and 1.4 mm pilot holes. Decreases in insertion torque with increasing pilot hole size have been previously reported.[16,19–21] The decreases are due to the fact that force is required to displace bone when inserting MSIs, especially for insertions into dense bone.[22] By fabricating larger pilot holes, less bone needs to be displaced, there is less compression on the adjacent bone as the MSI is inserted, and insertion torque decreases.

Pilot holes also produced significant decreases in pullout strength, which were proportionally greater between the 1.0 mm and 1.4 mm pilot holes than between the no pilot hole and 1.0 mm pilot holes. Decreasing pullout strength with increasing pilot hole size has been previously described.[16,21] Pullout strength of screws is dependent on the depth of thread insertion.[23] As pilot holes become larger, less of the screw's threads are able to engage into the cortical bone, resulting in decreased pullout strength. The MSIs with no pilot hole had 0.7 mm depth of thread engagement; the 1.0 mm pilot holes were able to engage their screw threads 0.6 mm into the cortical bone, while the 1.4 mm pilot holes had only 0.2 mm depth of miniscrew thread engagement. This explains why the MSIs inserted with no pilot hole and with 1.0 mm pilot holes produced similar pullout strengths. The difference in depth of thread engagement between the 1.0 mm and 1.4 mm pilot holes was greater, as reflected by the larger decreases in pullout strength. This suggests that the ideal pilot hole should reflect the minimum diameter of the miniscrew. Moreover, pilot holes that are too small (e.g., differences between miniscrew diameter and pilot hole greater than 0.6–0.7 mm) have been shown to have little or no effect on insertion torque.[19]

There was also a significant increase in insertion torque and pullout strength with greater bone density, which supports the implant literature.[14,18,19,24,25] For example, Friberg and colleagues[24] reported higher insertion torque for the human mandible than for the less dense maxilla. Greater bone density implies greater bone quantity, which requires higher torsional forces to advance screws during insertion.[22] Greater amounts of bone increase the amount of bone-to-implant contact[24] and greater engagement of bone by screw threads, both of which might be expected to require greater strength for screws to pull out.

Significant positive correlations were observed between insertion torque and pullout strength; these associations were stronger in areas of high-bone density with no or smaller pilot holes. The associations were as strong, or stronger, than previously reported.[20,26–29] They suggest that insertion torque and pullout strength possess similar attributes of primary stability with greater bone-to-implant contact. As the amount of bone-to-implant contact decreases, the two measures become less reliable indicators of primary stability.

Based on the patterns of variability observed, pullout strength is a more reliable measure of primary stability than insertion torque, especially when there are pilot holes. The reduction in reliability with pilot holes could be because of fluctuations in the insertion process (i.e., start/stop, slow/fast, etc.). Fluctuations in pilot hole formation result in an overdrilled hole, and such problems might be expected to be the greatest with a 1.4 mm–diameter bur. Debris produced during pilot hole formation could be another source of variability; the 1.4 mm pilot holes would have greater amounts of debris left in the site and could have caused greater variation in insertion torque measurements.

Based on the results of this study, pilot holes are recommended in high-density bone. Insertion torque for the high-density bone without pilot holes may exceed the range recommended by Motoyoshi and colleagues (5–10 Ncm).[8] If reductions in insertion torque are desirable, then the 1.0 mm pilot hole may be best because it decreased insertion torque by 32% while decreasing pullout strength by only 6.5%. The 1.4 mm–diameter pilot hole in high-density bone also fell within Motoyoshi and colleagues' recommended range; it decreased insertion torque and pullout strength by 55% and 35%, respectively. Nevertheless, more research is needed to determine whether different recommended insertion torque values are necessary with and without pilot holes.

Pilot holes exceeding the minimum diameter of the screw are not recommended in low-density bone. The 1.4 mm pilot hole in low-density bone produced insertion torque below the recommended range. To enhance the primary stability in low-density bone, MSIs should be inserted without pilot holes and with pilot holes no larger than the screw's minimum diameter. The decrease of insertion torque with the 1.0 mm pilot hole was 28.4%, which is within the recommended range, while pullout strength decreased by only 10.1%.

The primary limitation of this study pertains to the inability to directly transfer the effects identified into the clinical situation. While the synthetic bone used in the present study is well suited for controlling extraneous factors and focusing on the effects under consideration, actual bone is much more variable and might be expected to produce different magnitudes of difference. However, the patterns of difference associated with pilot holes and bone densities should be similar for synthetic and real bone.

CONCLUSIONS

1. The hypothesis that pilot hole size has no effect on insertion torque and pullout strength was rejected; insertion torque and pullout strength significantly decreased as pilot hole size increased, with greater effects in high-density than low-density bone.
2. The hypothesis that bone density has no effect on insertion torque and pullout strength was rejected; insertion torque and pullout strength significantly increased as bone density increased.
3. Insertion torque and pullout strength are positively correlated, with associations decreasing as pilot hole size increases and bone density decreases.
4. The 1 mm pilot holes provided the greatest reduction in insertion torque while maintaining pullout strength.

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