# **Original Article**

# An in vitro study of factors affecting the primary stability of orthodontic mini-implants

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#### ABSTRACT

**Objectives:** To evaluate the effects of mini-implant features (length, design, core diameter), insertion technique (insertion angle, cortical punch), and cortical bone depth and density on mini-implant primary stability. The effect of mini-implant reinsertion was also investigated.

**Materials and Methods:** Two hundred and sixty Infinitas mini-implants of two lengths (9 mm and 6 mm), two core diameters (0.8 mm and 0.9 mm) for an external diameter of 1.5 mm, and four designs (two tapered, external diameter 1.5 mm; two cylindrical, external diameters 1.5 mm and 2.0 mm) were inserted into synthetic bone blocks, and the maximum insertion torque (MIT) was recorded. The cortical layer of the blocks varied in density (30 and 50 lb per cubic foot) and depth (1 mm and 2 mm). Three angles of insertion (90°, 75°, and 60°) and two methods of insertion (direct and cortical punch) were tested. Forty mini-implants were also removed and reinserted.

**Results:** A significant increase in the average MIT occurred when cortical bone density increased and when mini-implants were reinserted. The 1.5 mm diameter cylindrical design had significantly lower MIT than the 1.5 mm tapered and the 2.0 mm cylindrical designs. The other variables did not have a significant effect on MIT.

**Conclusions:** Mini-implants achieved greater primary stability in higher-density cortical bone, and the 1.5 mm diameter tapered and 2.0 mm cylindrical designs offered greater primary stability than the 1.5 mm cylindrical design. Reinserting mini-implants resulted in significantly increased MIT, possibly because of blunting of the threads. (*Angle Orthod.* 2012;82:1022–1028.)

KEY WORDS: Mini-implants; Mini-screws; Insertion torque; Primary stability

#### INTRODUCTION

Mini-implants provide reliable three-dimensional anchorage, leading to predictable treatment outcomes and less reliance on patient cooperation.<sup>1</sup> Because mini-implants may be immediately loaded, they require adequate primary stability followed by a consolidating

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period of secondary stabilization. Hence, primary stability is regarded as the key indicator of success and varies according to several patient, mini-implant design, and clinical technique factors. The most important patient factors affecting primary stability appear to be the density and depth of the cortical bone. A positive relationship between cortical bone depth and insertion torque has been demonstrated by a number of studies.<sup>2–6</sup> Insertion and removal torque have also been reported to increase significantly with increased bone density in homogeneous artificial bone.<sup>7</sup>

Mini-implant design features (eg, body diameter and shape) have been reported to affect primary stability, with insertion torque reported to be higher for tapered than for cylindrical mini-implants.<sup>2,3,5,8</sup> This seems to be due to the effect of increasing diameter associated with the shape change.<sup>7,9</sup> Conversely, thread pitch and body length may not significantly affect torque.<sup>9–11</sup>

The insertion technique, such as the insertion angle and predrilling, may also influence primary stability. Mini-implants inserted at  $60^{\circ}$  to  $70^{\circ}$  to the bone surface have been shown to exhibit greater primary stability

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Figure 1. The mini-implants tested.

than those inserted at  $90^{\circ}$ .<sup>12,13</sup> Predrilling reduces miniimplant insertion torque, especially with larger-diameter drills.<sup>2,4,14</sup> Insertion torque also decreases as the predrilling depth increases, with the reduction being most pronounced within the cortical layer.<sup>2</sup>

Mini-implant stability can be assessed using insertion and removal torques, pullout strength, the Periotest, and resonance frequency analysis; however, insertion torque appears to be the most reliable and relevant measure of primary stability.<sup>2</sup> This study aimed to evaluate the effects of mini-implant features (length, design, core diameter), insertion technique (insertion angle, use of a cortical punch), and cortical bone depth and density on the insertion torque using a single mini-implant system. The effect of removal and reinsertion was also investigated because, clinically, when primary stability is inadequate or close root proximity is suspected, then a mini-implant may be reinserted in a different position.

#### MATERIALS AND METHODS

For this study, 260 self-drilling Infinitas mini-implants (DB Orthodontics Silsden, Ltd, United Kingdom) of seven types were tested (Figure 1, Table 1). Four types were commercially available at the time of the study, and the others were specifically manufactured to provide test variations in the widened cervical or tapered section of the mini-implant body and the core diameter. The tapered designs had an external diameter of 1.5 mm that widened to 2.0 mm in the cervical section, and the length of the 2.0 mm portion was denoted by the cervical taper shown in Table 1.

Artificial bone blocks were chosen over animal or cadaver bone as they have uniform cortical bone density and depth and are unaffected by desiccation. Four bilaminar blocks, length 170 mm and width 110 mm (Sawbones, Sawbones AB, Malmo, Sweden), were used to simulate cortical and cancellous bone. A 10 mm layer of cellular polyurethane foam of 10 pounds per cubic foot (pcf) density, representing cancellous bone,<sup>15</sup> was laminated with either a 1 mm or 2 mm sheet of solid polyurethane resin, representing typical cortical depth in human jaws.<sup>16</sup> The resins had 30 pcf or 50 pcf density to represent relatively dense maxillary and mid-range density mandibular cortices, respectively, which is in line with published clinical norms<sup>17</sup> and the Misch classification (Table 2).<sup>18</sup>

The standard insertion angle was perpendicular  $(90^{\circ})$  to the surface, with  $75^{\circ}$  and  $60^{\circ}$  angles as test variables. The use of a 1 mm diameter, 2 mm long cortical punch (drill) was tested in the 50 pcf cortical density blocks as this step is recommended with the Infinitas mini-implant system to reduce insertion torque in dense cortical bone.<sup>19</sup>

A grid of 10 mm squares was drawn on each of the bone blocks, and mini-implants were inserted at the grid intersections to ensure that each one was surrounded by artificial bone. Next, 300 mini-implant insertions were performed (260 insertions and 40 reinsertions): 10 insertions for each different combination of variables being tested (Table 3). To investigate the effect of reinsertion, the 40 type A mini-implants inserted at 90°, without the use of the cortical punch (Table 3), were removed by counterclockwise rotation, debrided using compressed air, and reinserted into new locations.

The mini-implants were inserted using a surgical implant system (Intrasurg 300, Kavo Dental Ltd, Amersham, United Kingdom), which recorded the maximum insertion torque (MIT) and was set to 25–35 rpm speed, 40 Ncm maximum torque, without irrigation. These settings are consistent with the manufacturer's recommendations. To ensure that mini-implants with differing neck lengths were inserted up to, but not beyond, the end of the thread, all shortneck implants were inserted with a 0.8 mm depth

Table 1. Characteristics of the Implants

Туре	Length, mm	External Diameter, mm	Core Diameter, mm	Cervical Taper, mm*	Neck Length	Number of Mini-implants		
А	9	1.5	0.8	0.75	Short	120		
В	9	1.5	0.8	0.5	Short	30		
С	9	1.5	0.8	0	Short	20		
D	9	2.0	1.3	0	Long	20		
Е	6	1.5	0.8	0.75	Short	20		
F	6	2.0	1.3	0	Long	20		
G	9	1.5	0.9	0.75	Short	30		

\* Denotes length of mini-implant for which the external diameter is 2.0 mm.

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Misch Bone-Density Grade	Physical Density, pcf	Radiographic Density, Hu	Usual Anatomic Site
D1	30–40	>1250	
D2	20–30	850-1250	Anterior mandible (1st premolar to 1st premolar)
D3	10–20	350-850	Anterior maxilla (2nd premolar to 2nd premolar)
			Posterior mandible (2nd premolars and molars)
D4	5–10	150–350	Posterior maxilla (molar region)
D5	<5	<150	

Table 2. Misch Bone Classification and Equivalent Physical and Radiographic Densities

elastomeric module fitted over the neck, and all longneck implants were inserted with a 1.4 mm depth orthodontic separator. Insertion stopped when the module or separator showed initial compression. A guide block, with three pairs of parallel lines at angles of 90°, 75°, or 60°, was used to standardize miniimplant insertion such that the implant driver was aligned between the parallel lines and lightly rested against the guide (Figure 2). For insertions preceded by the cortical punch, this was used in the handpiece with the same settings as for the 90° implant insertion.

Statistical analyses were performed using SPSS software (version 17, IBM UK Ltd, Middlesex, Portsmouth, UK), apart from the insertion vs reinsertion repeatability evaluations, which were performed using STATA software (version 11, StataCorp LP, College Station, Texas). Given the small number of cortical punch insertions performed (n = 20), these insertions were analyzed separately to the main data set. Data relating to variation in core diameter and insertion vs reinsertion were also analyzed separately.

A subjective assessment of box and whisker plots indicated that the data were not normally distributed, so nonparametric methods were used for the univariable analyses. The Mann-Whitney test was used to evaluate the effects of length, core diameter, cortical punch, and cortical bone density and depth. The Kruskal-Wallis test was performed to compare the MIT for the three insertion angles and the four designs of mini-implant. Where the Kruskal-Wallis test showed a significant difference in MIT between the groups, the results were analyzed further using the Mann-Whitney test to determine where the difference lay, applying a Bonferroni correction to avoid spuriously significant results arising from multiple testing. Variables found to be statistically significant at the 5% level were entered into a multivariable regression equation in which MIT was the outcome variable and the significance level was set at 5%. The assumptions underlying each multivariable regression analysis were checked by a study of the residuals and were found to be satisfactory only after a logarithmic transformation was taken of MIT. The MIT for the insertion and reinsertion groups was evaluated for repeatability using the Bland and Altman method and Lin's concordance correlation coefficient.

A power calculation was not indicated because of the complexity of regression equations. However, it is generally accepted that there should be at least 10 samples for every covariate within a regression equation, and this study was designed accordingly.

## RESULTS

## Length

The median MIT for 6 mm mini-implants (9.5 Ncm) was higher than that for the 9 mm mini-implants (8.6 Ncm), but the difference was not statistically significant.

Table 3. Details of the Mini-Implant Insertions

Length	Design: External Diameter/Cervical Taper, mm	Core Diameter, mm	Insertion Angle, $^{\circ}$	Cortical Punch	Reinsertion	Artificial Bone Blocks: Cortical Depth, mm/ Density, pcf			No. of	
mm						1/30	1/50	2/30	2/50	Mini-implants
9	1.5/0.75	0.8	90	No	No	10	10	10	10	40*
9	1.5/0.75	0.8	75	No	No	10	10	10		30
9	1.5/0.75	0.8	60	No	No	10	10	10		30
9	1.5/0.75	0.8	90	Yes	No		10		10	20
9	1.5/0.75	0.8	90	No	Yes	10	10	10	10	40
9	1.5/0.5	0.8	90	No	No	10	10	10		30
9	1.5/0	0.8	90	No	No	10	10			20
9	2.0/0	1.3	90	No	No	10	10			20
6	1.5/0.75	0.8	90	No	No	10	10			20
6	2.0/0	1.3	90	No	No	10	10			20
9	1.5/0.75	0.9	90	No	No	10	10	10		30
						100	110	60	30	300

\* Indicates mini-implants that were removed for reinsertion.



Figure 2. Mini-implant insertion at 75° using a guide block.

#### Design

See Figure 3 and Table 4 for design details. The median MIT was significantly lower for the 1.5/0 mm cylindrical group (6.9 Ncm) than for the 1.5/0.75 mm (9.3 Ncm), 1.5/0.5 mm (8.6 Ncm) tapered, and 2.0/ 0 mm cylindrical (8.9 Ncm) designs (P < .001, P =.042, and P = .002 respectively). There was no significant difference in median MIT between any of the other groups. The MIT for the 1.5/0.5 mm and 2.0/ 0 mm designs was not significantly different from that of the 1.5/0.75 mm design when cortical density was taken into account in the regression analysis. However, the MIT for the 1.5/0 mm design was significantly lower than that for the 1.5/0.75 mm design when cortical density was taken into account (P < .001). The partial regression coefficients represent the mean decrease (indicated by the negative signs) in  $\log_{10}$ MIT for the 1.5/0.5 mm, 1.5/0 mm, and 2.0/0 mm designs compared with the 1.5/0.75 mm design.

#### **Core Diameter**

The median MIT was greater for 0.9 mm core diameter mini-implants (8.0 Ncm) than for 0.8 mm mini-implants (7.2 Ncm), but the difference was not statistically significant.



Figure 3. Box and whisker plot showing the distribution of MIT for different designs of mini-implant.

#### **Insertion Angle**

The median MIT for the  $60^{\circ}$  (9.9 Ncm) group was higher than that for the  $90^{\circ}$  (8.9 Ncm) and  $75^{\circ}$  (8.5 Ncm) groups, but the difference between the groups was not statistically significant.

#### **Cortical Punch**

The median MIT was lower for insertions where the cortical punch had been (11 Ncm) used compared with those where it had not been used (12.5 Ncm), but this difference was not statistically significant.

#### **Cortical Bone Density**

See Figure 4 and Table 4 for details about cortical bone density. The median MIT for the 50 pcf cortical density (11 Ncm) was significantly greater than for 30 pcf density (7.5 Ncm) in the univariable analysis (P < .001). An increase in cortical bone density from 30 pcf to 50 pcf resulted in a mean increase in  $\log_{10}$  MIT of 0.143 Ncm after design had been accounted for in the regression analysis (P < .001).

#### **Cortical Bone Depth**

The difference in median MIT between the 1 mm and 2 mm cortical depth groups (8.8 Ncm vs 9.1 Ncm) was not statistically significant.

#### Reinsertion

The mean difference between the inserted and reinserted values of MIT was -3.159 Ncm. A paired *t*-test indicated there was a statistically significant systematic error (P = .002) between the paired measurements; the MIT on reinsertion was systematically higher

	Partial Regression	95% Confide			
Variable	Coefficient	Lower	Upper	Significance	
Constant	0.898	0.879	0.917	<i>P</i> < .001	
Cortical bone density	0.143	0.119	0.168	<i>P</i> < .001	
Design: 1.5/0.5 mm vs 1.5/0.75 mm	-0.023	-0.059	0.013	P = .203	
Design: 1.5/0 mm vs 1.5/0.75 mm	-0.131	-0.173	-0.089	P < .001	
Design: 2.0/0 mm vs 1.5/0.75 mm	-0.026	-0.058	0.006	P = .111	

Table 4. Log<sub>10</sub> Values for Partial Regression Coefficients, their 95% Confidence Intervals and P-Values for the Multivariable Regression

than that for the initial insertion. Lin's concordance correlation coefficient (r = .475) indicates that there was poor concordance between the initial and reinsertion MIT. Collectively, these statistical analyses indicate that mini-implant reinsertion resulted in a significantly higher insertion torque on average.

#### DISCUSSION

Artificial bone has been shown to be a good substitute for human bone in a number of studies investigating primary stability of mini-implants.5,7-9 Although such studies do not exactly replicate the clinical situation, they provide valuable standardized information on factors affecting mini-implant primary stability as this is dependent on mechanical retention. The mini-implant insertion method in this study was similar to that used in the clinical setting, which should make the results clinically relevant. However, it was not possible to completely standardise the insertion force or angle of insertion because insertions were performed manually rather than with a machine, and this may have influenced insertion torque. Insertion depth was dictated by either an orthodontic separator or a module placed around the neck of each miniimplant, in a similar way to that used by Chen et al.7 The compressible nature of these products may have



**Figure 4.** Box and whisker plot showing the distribution of MIT for 30 pcf and 50 pcf cortical densities.

resulted in small variations in insertion depth of the mini-implants tested and hence their insertion torque.

An increase in cortical density resulted in a significant increase in median MIT in this study. These results agree with the findings of animal and other artificial bone studies<sup>3,7</sup> and indicate that, for primary stability, mini-implants should be inserted in sites with adequate cortical bone density. However, it is important to remember that excessive insertion torque may cause ischemic necrosis, and consequently, poor secondary stability in vital bone; it also risks mini-implant fracture.<sup>7,8,20</sup>

The 1.5/0 mm cylindrical design mini-implants exhibited significantly lower MIT on average than the other designs tested in this study, which may be attributed to their smaller external diameter in the cervical portion of their body (1.5 mm compared with 2.0 mm). This suggests that tapered 1.5 mm diameter and 2.0 mm cylindrical designs offer better primary stability than the 1.5 mm diameter cylindrical design. Furthermore, 1.5 mm diameter tapered mini-implants appear to achieve similar insertion torgue to 2.0 mm cylindrical mini-implants. This is clinically relevant because many interproximal insertion sites may not accommodate a 2 mm diameter mini-implant.<sup>21</sup> Previous studies investigating the effect of design on primary stability have analyzed the diameter and taper effects separately, although these factors are codependent. When the results of this study were examined in the same way, they were concordant with other published studies: cylindrical mini-implants exhibited significantly lower MIT than those with a tapered body design,<sup>2,3,5</sup> and an increase in body diameter resulted in an increase in MIT.2,7,9,13

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Mini-implants that had been removed and then reinserted exhibited significantly higher MIT during the second insertion. This may be due to blunting of the threads, such that reinsertion MIT may not be a reliable indicator of primary stability. In lieu of more detailed research, it seems reasonable to either avoid reinsertion in areas of high cortical density or to consider predrilling.

The length of mini-implants did not significantly influence MIT in this study, in contrast with the results of a previous artificial bone study.<sup>9</sup> This disparity may be due to differences in the mini-implants and media tested. However, our results are broadly consistent with those of clinical studies that have found primary stability to be independent of mini-implant length.<sup>10,11</sup> This indicates that mini-implant length may be selected according to anatomical factors without primary stability necessarily being affected.

An increase in cortical bone depth from 1 mm to 2 mm did not result in a significant increase in average MIT in this study, in agreement with the findings of Salmória et al.<sup>22</sup> However, several other studies have reported a positive correlation between MIT and cortical depth.<sup>2,3,5,6</sup> The differences in these results may be due to differences in the mini-implants tested, the bone used, and the method of insertion. Overall, variations in cortical density may have more influence on primary stability than cortical depth, when the latter is between 1 mm and 2 mm.

Although there were no statistically significant differences between the three insertion angles tested in this study, the  $60^{\circ}$  insertion group had a higher median MIT than the  $90^{\circ}$  or  $75^{\circ}$  groups, in agreement with the findings of two animal studies.<sup>12,13</sup> These authors advised insertion of  $60^{\circ}$  to  $70^{\circ}$  to increase mini-implant stability, and although the results of the present study do not provide strong evidence, they are supportive of this advice. Insertion at less than  $90^{\circ}$  to the bone surface has also been suggested to reduce the likelihood of root contact,<sup>22</sup> and because insertion torque was not detrimentally affected by inserting mini-implants at  $75^{\circ}$  or  $60^{\circ}$ , the results of this study are also consistent with this guidance.

Use of a cortical punch tended to decrease the MIT, similar to predrilling in two animal studies.<sup>2,14</sup> However, this effect did not reach statistical significance, possibly because of the small number of cortical punch insertions performed here (n = 20).

An increase in core diameter from 0.8 mm to 0.9 mm resulted in an increase in average MIT, although this was not significant. Studies on fracture resistance have only examined external (thread and core) diameter changes,<sup>23,24</sup> but given the relationship between diameter and strength, it seems reasonable to consider that a 0.1 mm increase in core diameter should give greater fracture resistance while only causing a modest increase in insertion torque.

#### CONCLUSIONS

• An increase in cortical bone density caused a significant increase in MIT and, therefore, enhanced mini-implant primary stability. Cortical density may have more influence on primary stability than cortical depth, when the latter is between 1 mm and 2 mm.

- Mini-implant design and diameter influenced MIT such that the 1.5 mm tapered and 2.0 mm cylindrical versions achieved significantly greater primary stability than the 1.5 mm cylindrical design. MIT was also more affected by changes in external diameter than length.
- Reinsertion of mini-implants results in a significant increase in MIT.

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