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Original Article

Effect of Predrilling Diameter on Orthodontic Miniscrew Primary Stability

Chutimont Teekavanich* Masayoshi Uezono** Paiboon Techalertpaisarn*** Keiji Moriyama****

Abstract

Background: Predrilling diameter is a factor that is associated with miniscrew primary stability. However, no studies have reported on the relationship between predrilling sizes and shear force loaded as anchorage during orthodontic treatment. **Objective:** The purpose of this study was to evaluate the effect of 0.70, 0.80, 0.90, 1.00, 1.10, and 1.20 mm predrilling sizes on insertion torque and shear test using 1.30-mm diameter miniscrews in 1-mm thick synthetic cortical bone. **Materials and methods:** Insertion torque was recorded using a torque driver. The shear test was performed using a universal testing machine by loading a tangential force perpendicularly to the miniscrew at 1 mm/min until it was displaced by 0.50 mm. **Results:** Overall, the insertion torque tended to significantly decrease as the predrilling diameters increased. The exceptions were in the 0.70 and 0.80 mm groups that had insertion torque values lower than those in the 0.90 mm and 1.00 mm groups. Regarding the shear test, although there were no significant differences among the groups, the 1.20-mm predrilling diameter group demonstrated a much lower value, suggesting that it might be easier to dislodge after receiving an orthodontic force. **Conclusion:** Predrilling diameter size up to 77 % of the 1.30-mm outer diameter miniscrew can be used to achieve optimal orthodontic miniscrew primary stability.

Keywords: Insertion torque, Miniscrew, Predrilling diameter, Primary stability, Shear test

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Corresponding author: Chutimont Teekavanich
E-mail: praewteekavanich@gmail.com

* Lecturer, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand
** Assistant Professor, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, Tokyo, Japan
*** Associate Professor, Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand
**** Professor, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, Tokyo, Japan

Introduction

Orthodontic anchorage, defined as resistance to undesirable tooth movement,[1] has previously been achieved using teeth, intra-oral appliances and extra-oral appliances.[2] However, temporary anchorage devices have become widely used to obtain absolute anchorage, especially miniscrews, because of their advantages, e.g., smaller size, acceptable cost, simple insertion, less trauma, and do not require patient compliance.[3,4] However, miniscrew failure has been found to be ~13 %-20 %.[5]

Primary stability is important for miniscrew success due to the immediate loading that is applied on them, prior to osseointegration.[6,7] It is a mechanical interlock between the miniscrew surface and surrounding bone.[8] Several factors affect this initial stability, e.g., placement site characteristics, miniscrew characteristics, root proximity, and insertion methods.[7] Different techniques have been used to assess miniscrew stability, including a histological test (bone-to-implant contact) and mechanical tests (insertion torque, removal torque, pull-out strength, shear test, and percussion test).[9,10]

Miniscrew stability is most frequently evaluated by measuring the insertion torque, which represents the amount of torque required to overcome the bone resistance during miniscrew placement.[11] To achieve an acceptable success rate for typical orthodontic treatment, an insertion torque value ranging from 5-10 Ncm has been recommended.[12] In some situations, miniscrews need to resist much higher forces than usual, such as miniscrew-supported temporary pontics,[13] miniscrew-assisted rapid palatal expanders,[14] or molar distalizers.[15] To evaluate the miniscrew strength in these cases, a pull-out test is previously used to measure the maximum tensile force applied along the longitudinal axis of the screw to cause bone failure.[7,16,17] However, to exactly mimic the clinical use of miniscrews, a tangential force oriented perpendicularly to the screw should also be measured for more advantage, i.e., a shear test.[17] There were some studies evaluated miniscrew stability using shear force loaded to miniscrew head to examine the orientation for failure resistance[17] and the effect of miniscrew diameter,[10] but there is no report regarding the relationship between insertion torque and shear test.

There are various types of orthodontic miniscrews, divided into self-drilling and self-tapping procedures. Although the self-drilling type is easier to use and produces greater torque, it also creates more microdamage to the surrounding cortical bone,[18,19] Excessive amounts of damage can decrease the stiffness and strength of the cortical bone, leading to adverse complications, e.g., less stability and screw loosening.[19,20] Thus, one solution to reduce microdamage is to predrill through the cortical bone before miniscrew insertion. The recommended predrilling diameter has been previously reported, ranging from 69 %-77 %.[21,22] However, little is known about the relationship between predrilling size and shear force, which closely imitates the clinical procedure to evaluate primary stability.

Therefore, the objective of this study was to estimate the optimal predrilling diameter, varying in size of 0.70, 0.80, 0.90, 1.00, 1.10, and 1.20 mm, to evaluate the 1.30-mm miniscrew primary stability by measuring insertion torque and shear force. The null hypothesis was that there is no significant difference among the different predrilling sizes.

Materials and methods

1. Specimens

Sample size estimation was calculated using power analysis and a total of 30 has been decided for total sample size. Thirty titanium alloy miniscrews (1.30 mm diameter and 6 mm long, Jeil Medical Corporation, Seoul, Korea) were used in this study. Artificial cortical bone (1 mm thick) was prepared as a specimen (Sawbones, Vashon, WA, USA) to place the miniscrews in. The bone was cut into thirty 14-mm square pieces, using a low-speed precision cutter

Table 1 Physical and mechanical properties of the artificial cortical bone

Properties	Units
Density	1.70 g/mL
Ultimate tensile strength	90.00 MPa
Modulus of elasticity	12.40 GPa
Compressive yield strength	120.00 MPa
Compressive modulus	7.60 GPa

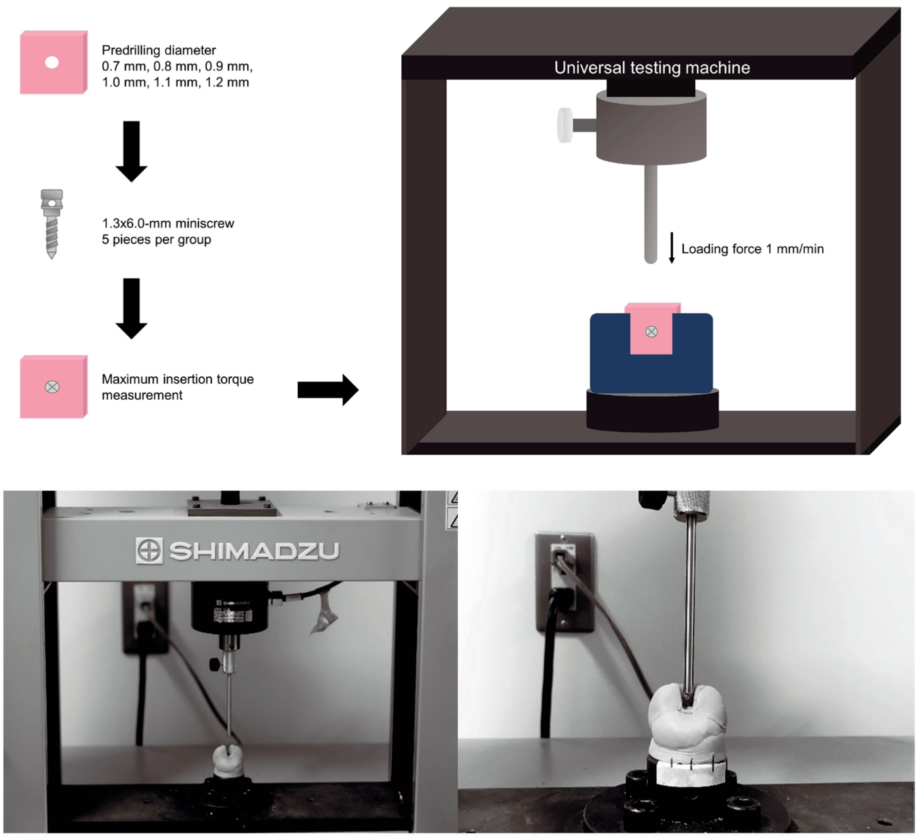

Figure 1 Images of the experiment; (A) Schematic image of the experiment process and (B) Image when a bone piece with the miniscrew was fixed with a customized silicone jig and a cylindrical rod connected to the universal testing machine was used to transfer the force

(IsoMet, Buehler, IL, USA). The physical and mechanical properties of the artificial bone are presented in Table 1.

2. Predrilling procedure

The thirty bone pieces were randomly divided into six groups (n = 5), one group each for miniscrews with a predrilling diameter of 0.70, 0.80, 0.90, 1.00, 1.10, and 1.20 mm. The center point of each piece of bone was marked with a pencil, and secured in a vice. The predrilling hole was drilled dry, perpendicular to the bone, with a cylindrical carbide bur in a micromotor. The holes were measured to confirm their accuracy using a light microscope (Nikon Instruments Inc., NY, USA) and NIS elements imaging software (Nikon Instruments Inc., NY, USA).

3. Miniscrew insertion

The bone piece was secured in the vice and a miniscrew was inserted into the predrilled hole manually by one examiner using a hand torque driver (Tohnichi, Tokyo, Japan) until the neck part was reached, approximately 1 mm under the head part. The maximum insertion torque was recorded.

4. Shear test

The shear test was performed using a universal testing machine (Shimadzu, Kyoto, Japan). The bone piece with the miniscrew was fixed with a customized silicone jig at the base of the machine to confirm its exact position. A cylindrical rod (5 mm diameter), connected to the machine was used to transfer the force and was set at the screw-bone interface before testing. A tangential force was loaded perpendicularly to the screw with a crosshead speed of 1 mm per minute. The procedure is illustrated in Figure 1. The miniscrews were displaced by 0.50 mm, which had been previously reported to not cause slippage.[10] The load-displacement data were recorded.

5. Statistical analysis

The pairwise Wilcoxon rank sum test adjusted with the Hochberg method ("R" software (version 4.2.3, http://www.r-project.org/, accessed on 5 July 2023)) was used to examine the effect of the predrilling diameter on the insertion torque value and shear force. P values < 0.05 were considered significant.

Results

The maximum insertion torque ranged from 2.00-8.90 Ncm. The mean insertion torque from 0.70 mm to 1.20 mm predrilling diameters was 7.46, 6.74, 8.70, 8.02, 4.32, and 2.12 Ncm, respectively. Screws with larger predrilling diameters had significantly (P < 0.05) lower insertion torques compared with those from 0.90 mm to 1.20 mm. However, the 0.70 mm and 0.80 mm predrilling size groups demonstrated

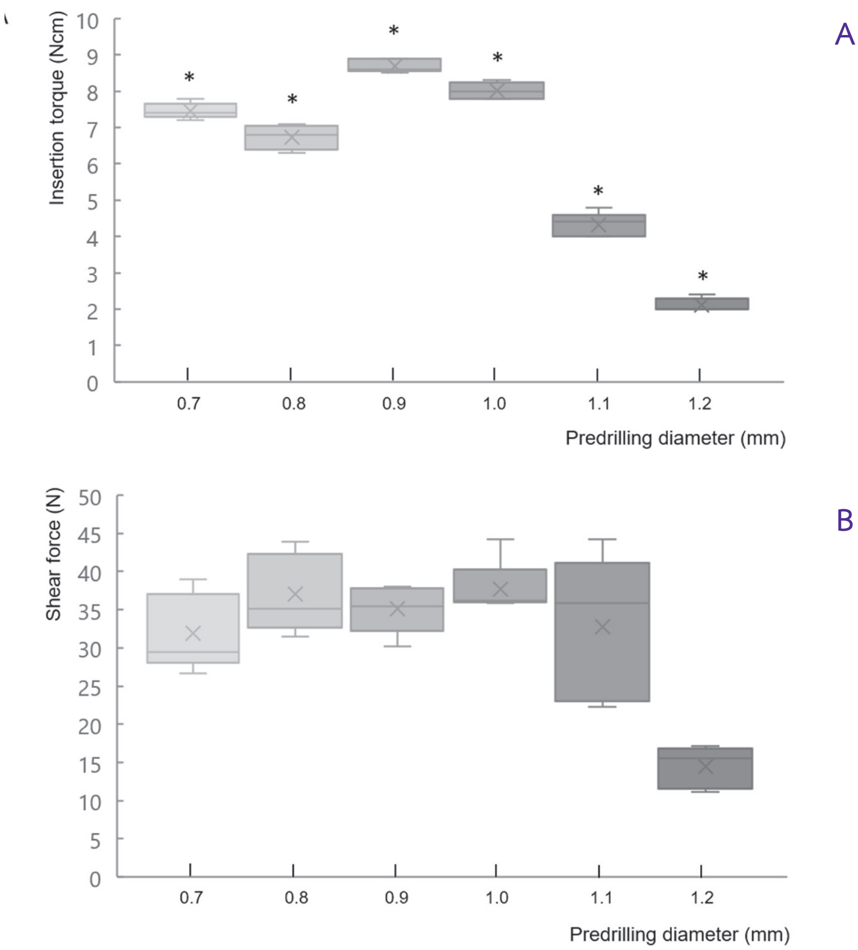

Figure 2 Box-plot graphs of (A) insertion torque test and (B) shear test. The asterisk represents significant differences among all groups (P < 0.05)

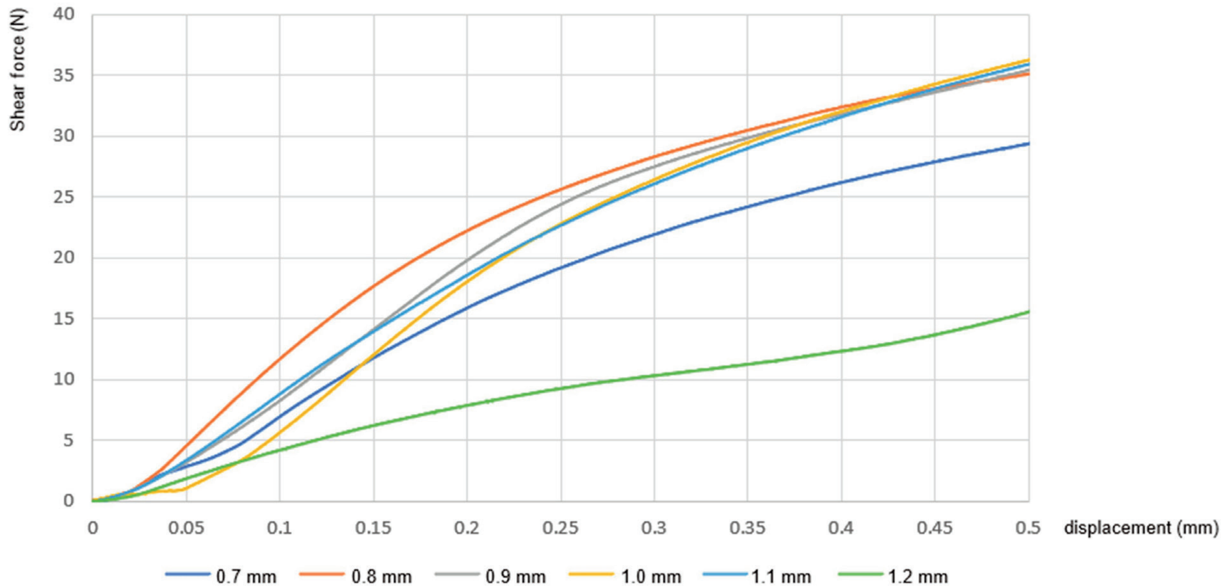

Figure 3 Mean shear force values vs. miniscrew displacement of the six predrilling diameters.

significantly lower insertion torque than that of the 0.90 mm predrilling diameter group (Figure 2A).

Regarding the force loaded at 0.50 mm screw displacement, the statistical analysis found no significant differences among the six groups. The mean shear force value in the 0.70 mm to 1.20 mm predrilling diameter group was 31.90, 36.99, 35.11, 37.69, 32.80, and 14.46 N, respectively (Figure 2B). A similar trend was shown in all groups when the screws were displaced up to 0.50 mm. However, the 1.20-mm predrilling diameter group presented a much lower force load to move the miniscrews 0.50 mm than the other groups (P = 0.087) (Figure 3).

Discussion

This study was to evaluate the relationship between miniscrew predrilling diameters, insertion torque and shear test. Even though there are several articles published about the influence of miniscrew insertion torque on primary stability, the sizes of miniscrew were quite large when planning to use between roots.[12,23,24] The reason for choosing 1.30 mm diameter miniscrews as a testing material is that small screws have been increasingly used to avoid tooth root contact due to the root proximity when inserted inter-radicularly, causing root damage and miniscrew failure.[25,26] Furthermore, large diameter miniscrews can produce more microdamage to the surrounding cortical bone, which can compromise their stability.[27] However, miniscrews that are too small tend to fracture more easily during placement and removal.[28] Based on their results, Poggio et al[29] recommended to use miniscrews ranging from 1.20-1.50 mm in diameter when inserted inter-radicularly.

Most previous studies have determined that the insertion torque value was influenced by the predrilling size, finding that the larger the predrilling diameter, the lower the insertion torque.[30,31] This is because less bone needs to be displaced during miniscrew insertion when using a larger predrilling size. However, the present study revealed that the insertion torque values when the predrilling diameter was 0.70 mm and 0.80 mm were lower than those of 0.90 mm and 1.00 mm, while a 0.70 mm predrilling size caused a larger insertion torque than for the 0.80-mm size. Several previous studies also reported this unexpected result. Wilmes et al[31] reported that the insertion torque of a 2-mm diameter miniscrew was higher when inserted into a larger pilot hole. The authors claimed that a smaller predrilling size may result in miniscrew fracture. Another result from Battula's study,[32] using bone screws for rigid fixation, also showed that the highest insertion torque value was not from the smallest predrilling diameter with no further discussion.

One factor that may explain these results is the effect of the cutting flute, which is a recessed area usually placed at the tip of the miniscrew. Adding this flute results in decreased miniscrew surface area, leading to decreased friction and insertion torque because the flute can clear more bone debris accumulated around the threads if it is wide enough.[33,34] According to a previous study using micro-CT to examine the cross-sectional view of the cutting flute of a 1.30-mm miniscrew, it found that the cutting flute area was larger at 0.70-mm cross-sectional diameter and almost gone at 0.90-mm cross-sectional diameter. This can cause lower insertion torque values in 0.70-mm and 0.80-mm predrilling groups than that of 0.90-mm group. Additionally, the flute also produced more plastic deformation with an 0.80-mm predrilling diameter, causing smaller insertion torque values of this group.[21]

Regarding holding power, previous studies mainly evaluated the effect of predrilling size using pull-out strength to measure the maximum vertical force that miniscrew can resist. Hung et al[30] found that there was a significant decrease in the pull-out force when predrilled with a larger diameter because of less thread-cortical bone engagement. Furthermore, they also suggested using pull-out strength rather than insertion torque for measuring primary stability because the insertion torque method produced greater variation. However, both methods had a strong correlation, thus they can still be used effectively.[7,30] But in our experiment, we focused on the shear force, oriented perpendicularly to the screw, to imitate the clinical situation. Shear force was found to be lower compared with the pull-out force due to the thread axis that provides maximum resistance when there is a force perpendicular to them.[17] Although no significant differences of shear test among the predrilling size groups were found in this study, the 1.20-mm predrilling diameter group demonstrated less loaded force to move the miniscrews than others, which may cause easier screw loosening clinically.

Considering the optimal predrilling diameter, there is a recommended insertion torque value.[12] Our results indicated that the insertion torque that matches the recommendation of 5-10 Ncm is obtained from 0.70-mm, 0.80-mm, 0.90-mm, and 1.00-mm diameter predrilling sizes. Furthermore, there is also a recommended ratio of the predrilling diameter to achieve miniscrew stability. It is suggested that the drill diameter should be less than 80 % of the screw's external diameter, based on pull-out strength testing,[35] or should be between 69 % and 77 % of the outer diameter for a 1.30-mm miniscrew when assessing by the bone-to-implant contact ratio.[22] A recent study evaluating the microdamage of the cortical bone also suggested a ratio of 77 % to obtain the greatest primary stability.[21] Our results supported these studies by showing that predrilling from 0.70-1.00 mm, which are 53.80 % -76.90 % respectively, should be performed to obtain optimal insertion torque value and shear force resistance. Hence, regarding all aspects, 77 % is the most appropriate size of predrilling diameter to enhance miniscrew primary stability.

The major limitation of this study is the difference between synthetic and living cortical bone. Although synthetic bone is the most appropriate material for biomechanical testing due to its availability and uniformity, the results cannot be directly transferred into clinical situations. Further research using animal or cadaver bone, as well as clinical study is still needed to achieve the most advantage of using orthodontic miniscrews.

Conclusion

The appropriate predrilling size ranges from 57 to 77 % of 1.30-mm diameter miniscrews when insertion torque and shear force were examined to acquire greater primary stability, indicating less mobility and failure of orthodontic miniscrew.

Author contribution

CT: Conceptualization, Methodology, Software, Formal analysis, Resources, Data curation, Writing-Original draft preparation, and Visualization; MU: Conceptualization, Software, Validation, Investigation, Resources, Writing-Review and Editing, and Supervision; PT: Supervision, and Project administration; KM: Supervision, and Project administration; CT and MU have made an equal contribution to this study; All authors have read and agreed to the published version of the manuscript.

Disclosure statement

Authors have no the conflicts of interest.

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