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ORIGINAL ARTICLE

Effect of Angular Insertion of Orthodontic Miniscrews on Primary Stability

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ABSTRACT

Purpose: **Infrazygomatic crest (IZC) miniscrews have useful clinical applications. They are applied with angular insertion to the bone surface. However, appropriate angles for the maximum stability of the miniscrew have not yet been well documented. This study aimed to compare the primary stability of different angles of orthodontic miniscrew insertion by analyzing maximum insertion torque (MIT) and pull out strength (PS).**

Materials and methods: **Sixty miniscrew implants were divided into 3 groups which underwent different angular insertion, with 20 samples in each group. Three pairs of bearing devices were constructed with an angulation of 30, 40 or 50°. An angulation of 30, 40 or 50° were tested with synthetic bone block. MIT and PS were measured by the digital torque gauge and universal testing machine. The data was then subjected to statistical analyses.**

Results: **The 30-degree group had a significantly greater MIT compared with the 40- and 50-degree groups while the MIT of 40- and 50-degree groups were not significantly different. The 50-degree group had significantly greater PS than that of the 40-degree group in which the PS was also significantly greater than in the 30-degree group.**

Conclusions: **As the angular insertion of 30° showed the greatest maximum insertion torque, IZC miniscrew placement at 30° to the bone surface should be employed in cases where there is enough buccal bone thickness; however, further studies are necessary to draw more definite conclusions concerning the benefits of angular insertion.**

Keywords: Orthodontic miniscrews; Angular insertion; Primary stability; Maximum insertion torque (MIT); Pull out strength (PS)

In recent years, the use of orthodontic miniscrew as an absolute anchorage has begun to offer wider treatment capabilities as well as increased efficiency.[1,2] The use of orthodontic miniscrews has also led to more favorable treatment outcomes in many complexities, such as posterior maxillary teeth intrusion, mesial root movement for closure of extraction space, or maxillary whole arch distalization.[2,3] Orthodontic miniscrews have great mechanical retention together with several other advantages, including having sufficient anchorage in noncompliant patients, being minimally surgically invasive, allowing simplicity of insertion and removal, and being relatively not expansive.

Liou et al. recommend the infrazygomatic crest (IZC) as a placement site in the maxilla for orthodontic miniscrews.[4] The IZC is a pillar of cortical bone at the zygomatic process of the maxilla. It is a bony ridge running along the curvature between the alveolar and zygomatic processes and is located above the maxillary first molar in adults. The outer surface of the IZC is nearly perpendicular to occlusal plane. Liou et al. suggested orienting screws about 55−70° relatively above the occlusal plane to achieve maximal buccal bone engagement.[4] In that situation, miniscrews would be angled about 30−50° to the IZC bone surface. However, the appropriate angles for the stability of the miniscrew in the IZC have not yet been well documented.

Previous studies discussed the benefits of angular insertion.[5,6] In some cases, the placement of

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miniscrews at inter-radicular areas may damage the roots. To avoid this complication, the miniscrews should be placed into the alveolar bone below the roots, even though, it may result in an over-abundant vertical force. To prevent root trauma, angular miniscrew insertion has been introduced to replace perpendicular insertion to inter-radicular areas because more space is available at the bucco-apical region.[5,7] Moreover, the head positions of the miniscrews are close to the occlusal plane by angular insertion; it could be speculated that the line of action or vector of force will be closer to the center of resistance of the teeth.[8]

The angular placement of miniscrews also increases their contact surface with the bone.[7–10] Deguchi et al. also found that the cortical bone thickness in 30-degrees angular insertion of miniscrews was 1.5 times thicker than that of 90-degree insertion.[5] The thicker cortical bone increases the more primary stability of the miniscrews.[11] However, an overly acute angular insertion would cause bone stripping and inevitably result in miniscrew failure.

Wilmes et al. found that 70- degree angular insertion produced greater maximum insertion torque than those of 30, 40, 50, 60 or 90°. Therefore, they suggested that an insertion angle ranging between 60 and 70° produced the greatest maximum insertion torque.[10] However, Raji et al. found that 45-degree angular insertion produced greater maximum insertion torque than 75- or 90- degree angular insertion.[12] This finding was against the former report. Further study the primary stability of angular insertion smaller than 45° would be needed.

The primary stability of orthodontic miniscrews can be evaluated by the mechanical retention between the surface of the miniscrew and the surrounding bone,[11] while osseointegration is not essential. Sufficient primary stability is an important factor when assuming that the miniscrew is firmly attached to the jaw bones and ready to be used efficiently as intended. Therefore, primary stability also reflects the viability and success rate of orthodontic miniscrews in vitro.[6] Maximum insertion torque and pull out strength are the two determinants of primary stability; greater maximum insertion torque results in higher success rates of orthodontic miniscrew placement. If the maximum insertion torque is too high, the damage to the surrounding bone could result in osteonecrosis.[13]

As described earlier, results from past studies have varied, and further understanding of primary stability from angular insertion of miniscrews could provide useful clinical information. The aim of this study, therefore, was to compare the maximum insertion torque and pull out strength achieved by different angles of insertion of orthodontic miniscrews.

MATERIALS AND METHODS

Sixty miniscrews (TW Plus Co. Ltd, Pathumthani, Thailand) were used in this study. The miniscrews were designed with a tapering shape and an outer diameter of 1.8 mm, a total length of 14.3 mm, a thread length of 8 mm and a neck of 3.5 mm long. The miniscrews were randomly divided into 3 groups, 20 samples in each group, to study the primary stability at different angular insertions of 30, 40 and 50° to the synthetic bone surface (Sawbones, Pacific Research Laboratories, Vashon Island, WA, USA). The synthetic bone was made of polyurethane foam consisting of 1.2 mm cortical bone layer with a density of 0.32 g/cm^3 (20 pcf) and an 18.8 mm cancellous bone layer with a density of 0.16 g/cm^3 (10 pcf).[14,15] The synthetic bone was cut into 14 × 14 × 20 mm cubical bone blocks.

Three pairs of bearing devices were constructed with an angulation of 30, 40-or 50-degrees. A synthetic bone block was held on one side of each bearing device while a digital torque gauge (IMADA model HTGA-2N, Imada Inc., IL, USA) was held on the other. The miniscrews were connected to a driver rod fixed to the digital torque gauge (Figure 1).

The miniscrews were inserted into the synthetic bone block with a constant speed of 12 rounds per minute and terminated after the thread of the miniscrews was completely inside the synthetic bone (Figure 2) as in clinical use. The maximum insertion torque was recorded in newton-centimeters (N-cm).

The pull out strength was tested using a universal testing machine (UTM) (Instron model 5566, Instron Limited, MA, USA). The experimental model was fixed onto the synthetic bone block holder, which was attached to the lower part of the UTM (Figure 3). The miniscrew head was grasped using a clamp (Boasch Inc., Gerlingen-Schillerhöhe, Germany) which was attached to the upper part of the UTM, which UTM was operated with a crosshead speed of 10 mm/min. The maximum pull out strength was recorded in newtons (N) as pull out strength.

Statistical analysis

Maximum Insertion torque and pull out strength had normal distribution. The differences in insertion torque and pull out strength between the test groups were determined using the One-way

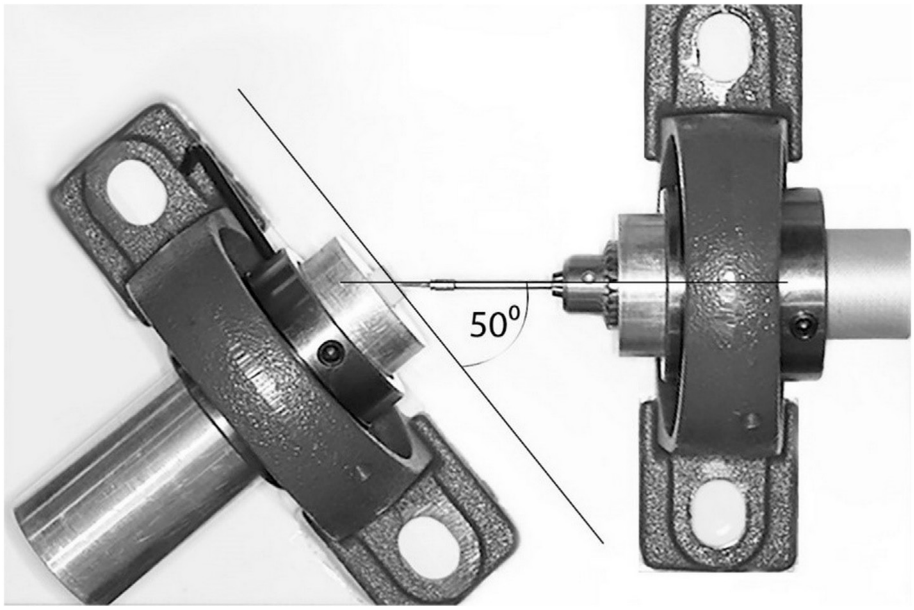

Figure 1. The miniscrew was inserted into the synthetic bone block with an angular insertion of 50°.

ANOVA test followed by the Tukey's post-hoc test ($p < 0.05$).

RESULTS

The mean and standard deviation of the maximum insertion torque and pull out strengths are shown in Table 1. The angular insertion of 30-degrees showed the greatest mean maximum insertion torque but the lowest pull out strength. With increasing angulation from 30° to 50°, the mean maximum insertion torque value decreased, whereas the mean pull out strength showed a gradual increase.

Different superscript letters indicate statistically significant differences with $p < 0.05$.

The data satisfied the normality of distribution, and the homogeneity of variance assumptions was equal. One-way ANOVA test showed a statistically significant difference in the mean maximum insertion torque and pull out strength between the three groups. The multiple comparison of the maximum insertion torque and pull out strength was calculated using Tukey's post-hoc test. Results showed that the mean maximum insertion torque of the angular insertion of 30-degrees was significantly greater than that of 40-and 50-degrees ($p < 0.05$) whereas there was no significant difference in the mean maximum insertion torque of the angular insertions of 40-and 50-degrees.

As the insertion angle increased, the pull-out strength rose significantly. An angular insertion of 30°, which was the smallest angle of insertion, produced the least pull out strength and was significantly less than those with angular insertions of both 40 and 50°.

DISCUSSION

Primary stability of orthodontic miniscrews can be determined with the mechanical retention between the miniscrew surface and the surrounding bone. Previous studies reported that the greater the maximum insertion torque, the greater the primary stability.[6,12,13]

The angles of insertion investigated in the present study (30, 40-and 50-degrees) were those same as what was recommended by Liou et al.[4] Their study recommended the insertion of IZC miniscrews at 14–16 mm above the maxillary occlusal plane and maxillary first molar with an angle of insertion of between 55 and 70° to the maxillary occlusal plane because there is adequate thickness of IZC at this position. This angle of insertion makes a 30-to 45° angle to the bone surface.

Meira et al. had studied the primary stability of 45, 60 and 90 degrees of insertion and concluded that a decreased angle of insertion of the miniscrew resulted in an increased maximum insertion torque.[16] In the same way, Raji et al. found that the greatest maximum insertion torque was generated by a 45-degree angular insertion, followed by 60- and 75-degree angular insertion, respectively.[12] The result of our study was consistent with both studies and showed the result of angular insertion smaller than 45°. Maximum insertion torque of miniscrews

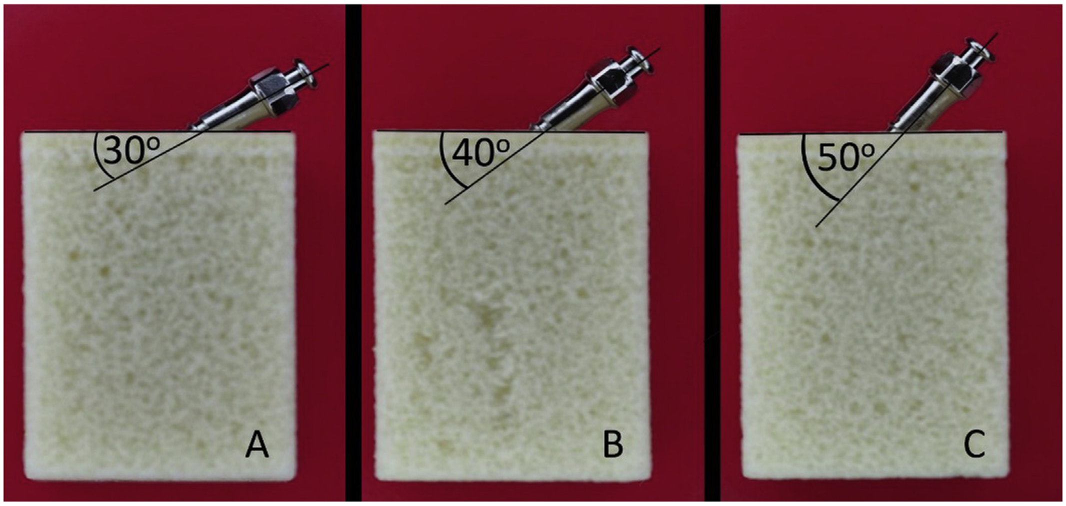

Figure 2. Experimental models. The miniscrews were inserted into the synthetic bone blocks with an angular insertion of 30° (A), 40° (B) and 50° (C).

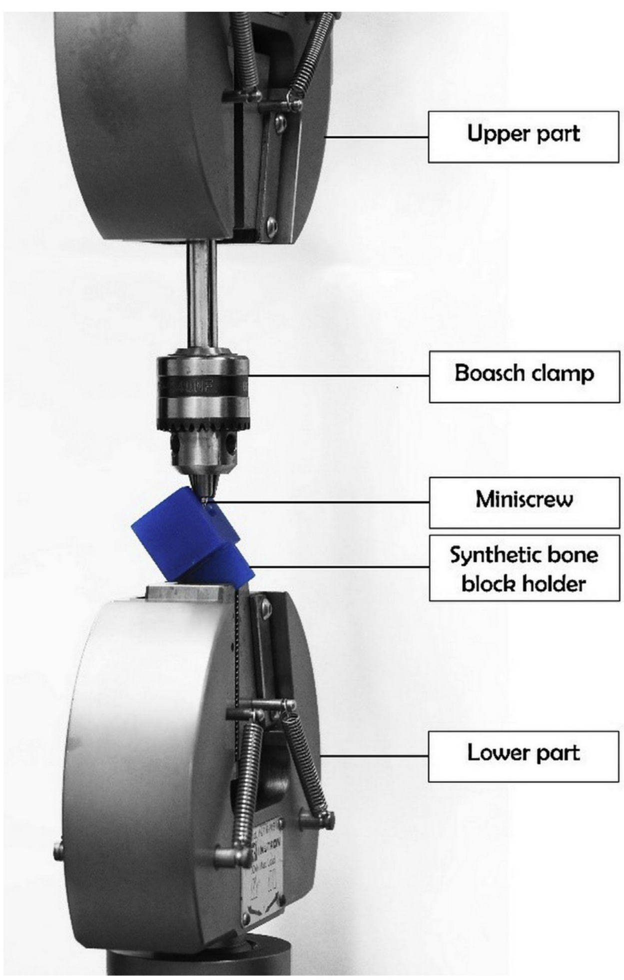

Figure 3. Pull out strength testing. The experimental model was set in the UTM.

at a 30-degree angle was significantly greater than those of the 40- and 50-degree angular insertion ($p < 0.05$). It pointed to the conclusion that the lesser angle of insertion of the miniscrews, the more surface contact area with the cortical bone, resulting in a greater maximum insertion torque.

Wilmes et al. reported that 70-degree angular insertion produced greater maximum insertion torque than those of 30, 40, 50, 60 or 90°.[10] They used ilium segments of a pig in their experiment. The difference in compact bone thickness and irregular bone surface affected the insertion torque and the angle of insertion respectively. The result conflicted with the research findings of Meira et al. in which synthetic bone was made of polyurethane foam similar with the structures of cortical and cancellous bone layers.[16] Raji et al. used poly-carbonate plates for controlling bone homogeneity.[12] Synthetic bones are reliable for in vitro study.

Another benefit of 30-degree to the bone surface at the IZC is that it minimizes the risk of root damage.[17] On the other hand, the more apical placement and less angulation of miniscrew insertion greatly increases the risk of maxillary sinus perforation[17,18]; however, a minimal perforation into the maxillary sinus could increase the miniscrew retention from becoming a bicortical screw. Liu et al. reported that a less than 2 mm-deep perforation into the maxillary sinus in clinical practice allows for normal healing.[19] While Jia et al. recommended the penetration through double cortical bone plates and the penetration depth should be limited for less than 1 mm.[20]

Miniscrews inserted at less than 25° to the bone surface may cause slippage of the miniscrew and can result in bone stripping and fracture.[4,21] To

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Table 1. Maximum insertion torque and pull out strength (Mean ± SD).

Test	Angle of insertion		
	30°	40°	50°
Maximum insertion torque (Ncm)	4.92 ± 0.10[a]	4.68 ± 0.10[b]	4.67 ± 0.06[b]
Pull out strength (N)	51.35 ± 2.41[a]	70.38 ± 2.23[b]	83.50 ± 1.73[c]

prevent trauma to bone, predrilling process should be employed to let miniscrew come into contact with compact bone and promote more insertion torque.

A serious complication during miniscrew insertion at the IZC is injury to the mesiobuccal root of the maxillary first molar with attendant maxillary sinus perforation[5,20]; therefore, to decrease that risk, dental CT imaging could be performed prior to the placement of miniscrews. Dental CT imaging gives information regarding the buccal bone thickness in relation to the roots and maxillary sinus.[5,22] The image helps the operator to select the length, angulation and position of the miniscrew to avoid trauma to roots and maxillary sinus. In cases where there is enough buccal bone thickness, IZC miniscrew placement at 30° should be employed.

Our results showed that the pull out strength of the miniscrews significantly decreased as the angle of insertion increased. This result is consistent with the findings of Aranyawongsakorn et al. who found that pull out strength decreased as the angle of insertion decreased among miniscrews implanted at 30, 45 or 60°, although the differences were not statistically significant.[23] The reason for this finding might be that the lower angle of insertion of the miniscrew resulted in less penetration depth[24]; consequently, the miniscrew was less resistant to the pull out force. Furthermore, the smaller penetration depth of the miniscrew resulted in more distance between the miniscrew head and the cortical bone, so that the protruding head and neck of the miniscrew experienced more movement, rendering the procedure prone to failure.[24,25] Therefore, orthodontic force should be applied carefully in cases of lower angle insertion. To mitigate this drawback, orthodontists should select longer miniscrew bodies.

Clinically, orthodontic force is not applied parallel to the miniscrew. In addition, axially pull out tests are mainly used in orthodontics for assessing biomechanical performance of miniscrews and comparing the results with those of previous study.[26] In this study, pull out force was applied axially to the miniscrew to evaluate the stability of miniscrews based on their contact with cortical bone following the earlier described application.[27] Although tangentially directional loading was close to clinically orthodontic loading situations, standardized and reproducible results in cantilever bending were unable to obtain. It would be reasonable to expect that such cantilever tests would result in large variations in pull out strengths.[26]

A few studies have found that different methods of force application had an impact on the chance of failure.[28,29] The more closely the long axis of the miniscrew approximates to the line of applied force, the greater the stability of the miniscrew, and the greater its resistance to failure.[29] Further studies regarding the effect of different direction of orthodontic pull force application on the pull out strength of different angular inserted miniscrews could be benefit in clinical orthodontic treatment.

The success of miniscrew placement depends on multiple other factors including presence of inflammation around the miniscrew.[30] Increasing the distance between the miniscrew and the root surface also significantly improves success rates.[6,9] Further in vivo studies can help gain a better understanding of angular insertion of IZC miniscrew and its application.

CONCLUSION

1. The angular insertion of 30° showed the greatest maximum insertion torque.
2. In cases where there is enough buccal bone thickness, IZC miniscrew placement at 30° should be employed. However, further studies are necessary to draw more definite conclusions concerning the advantages of using angular insertion.

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