CHAPTER 5

INFLUENCE OF INSERTION ANGULATIONS OF MINISCREW IMPLANT ON THE MECHANICAL RETENTION[2]

5.1) Introduction

Recently, several miniscrew implants have been specially developed to provide skeletal anchorage during orthodontic treatment (Costa *et al.*, 1998; Kanomi, 1997; Kyung S.H. *et al.*, 2003a; Maino *et al.*, 2003; Paik *et al.*, 2002; Park *et al.*, 2001; 2002). The small size, allied to relatively low cost and the ability to insert them in the dentoalveolar bone between the roots of adjacent teeth, has made the miniscrew implants a promising choice in terms of skeletal anchorage in orthodontics (Chung *et al.*, 2004; Kanomi, 1997; Kyung H.M. *et al.*, 2003; Lin and Liou, 2003; Maino *et al.*, 2003; Paik *et al.*, 2002; Park *et al.*, 2001).

Although these miniscrew implants have confirmed their exceptional clinical advantages in providing skeletal anchorage, the potential risk of damaging anatomical structures, such as injury to the dental roots and perforation of the maxillary sinus during placement procedures has become a main concern (Herman and Cope, 2005; Melsen, 2005; Melsen and Verna, 2005).
Systematic protocols of miniscrew implant placement using radiopaque markers, such as custom-made stents (Cousley and Parberry, 2006), surgical guides (Bae *et al.*, 2002; Suzuki and Buranastidporn, 2005) and templates (Kyung S.H. *et al.*, 2003b; Wu *et al.*, 2006) for transferring the pre-operative radiographic planning information to the surgical site, have been suggested as a practical method for guiding the miniscrew implant placement in the interproximal space of the selected implant site. Moreover, the use of 3-D surgical guide devices has shown the ability of outlining accurately the planned insertion angulation of the miniscrew implant preoperatively, therefore allowing for safe and predictable miniscrew implant placement in the dentoalveolar area.

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[2] Thai version of this chapter was submitted for publication in the Journal of Dental Association of Thailand and the results of chapter 5 were presented at the 6th AIOC, Taiwan (see Appendix C on page 88).

The use of insertion angulations during miniscrew implant placement have been recommended as a practical clinical approach to reduce the risks of damaging the dental roots of adjacent teeth in the dentoalveolar area (Aranyawongsakorn *et al.*, 2007) as the dental roots tend to diverge apically (Deguchi *et al.*, 2006; Ishii *et al.*, 2004; Schnelle *et al.*, 2004). Moreover, it has been theoretically suggested that the use of such insertion angulation would provide an increase in the surface contact area between the miniscrew and bone, thus improving the mechanical retention of the miniscrew to the bone (Deguchi *et al.*, 2006).

However, the influence of such insertion angulations on the biomechanical performance of miniscrew implants placed in the dentoalveolar bone has not been extensively investigated.

Therefore, the purpose of pilot study II was to investigate the effects of insertion angulations on the biomechanical performance of the miniscrew implants placed in the dentoalveolar bone of swine model.

5.2) Materials and methods

5.2.1 Sample

Three hundred and sixty self tapping titanium miniscrew implants with 1.6 mm diameter and 8 mm length (ACR Mini-Implant, BioMaterials Korea. Inc., Guro-gu, Seoul, Korea) were used in this experiment.

Sections of dentoalveolar bone extracted from the maxilla and mandible of ten crossbred swine, 4-5 months of age and with an average body weight of 80 kg were used during the mechanical test. Unnecessary portions of bone were removed and all soft tissues were dissected. According to the site of miniscrew placement, the samples of maxilla and mandible were divided into 3 distinct groups for the analysis; anterior, middle and posterior. The samples were frozen in saline-soak gauge at -20 degrees Celsius and on the day of testing, the samples were defrosted to room temperature.

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5.2.2 Miniscrew implant placement procedures

In accordance to the experiment design, miniscrew implants were inserted systematically in the dentoalveolar area of the maxilla and mandible with three defined angulations; 30, 60 and 90 degrees to the bone surface. At each selected implant site, a minimum clearance of 3 mm between miniscrew implants was preserved (Figure 5.1). Custom-made 3-D surgical guides were prepared to assure precise insertion angulations (30, 60 and 90 degrees) during the drilling and miniscrew implant placement to the bone surface (Figure 5.2).

Miniscrew implant placement were carried out using the insertion protocol described by Suzuki and Buranastidporn (2005). A 1.1 mm-diameter spiral drill was used to create the pilot hole into the cortical bone. A slow drill speed (400-500 rpm) was used with normal saline irrigation to avoid excessive heat generation and to remove the bone debris. Miniscrews were inserted into the bone with a manual hand-driver, following the manufacture's recommendation.

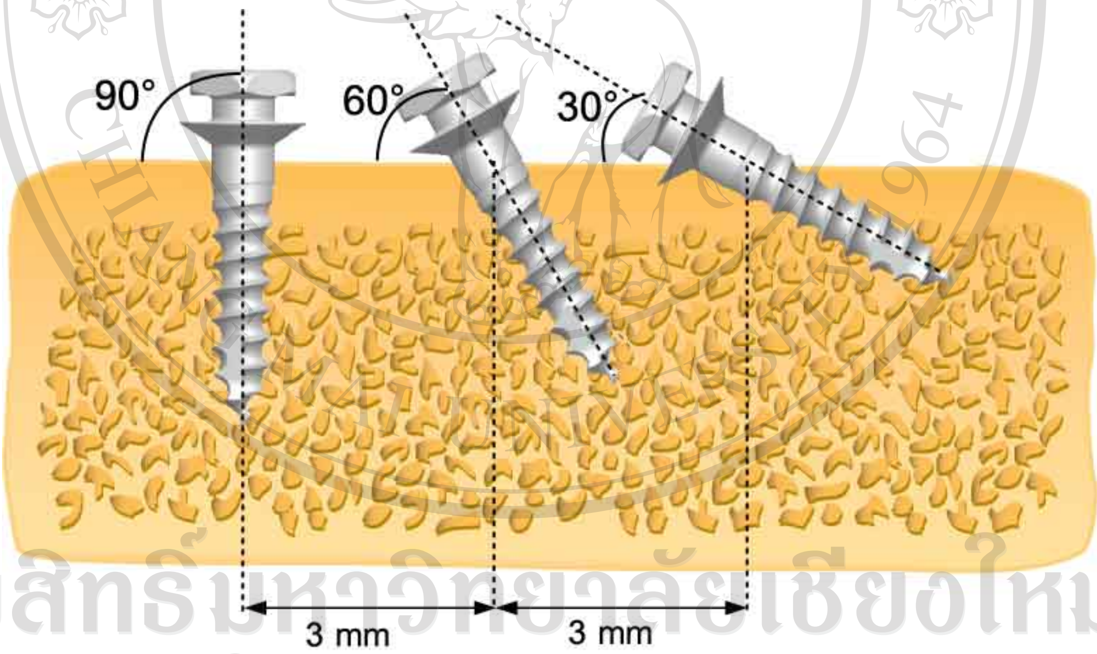

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Figure 5.1 Diagram of miniscrew placement. Miniscrews were inserted at 30, 60 and 90 degrees to the bone surface. A minimum clearance of 3 mm between miniscrew implants was maintained.

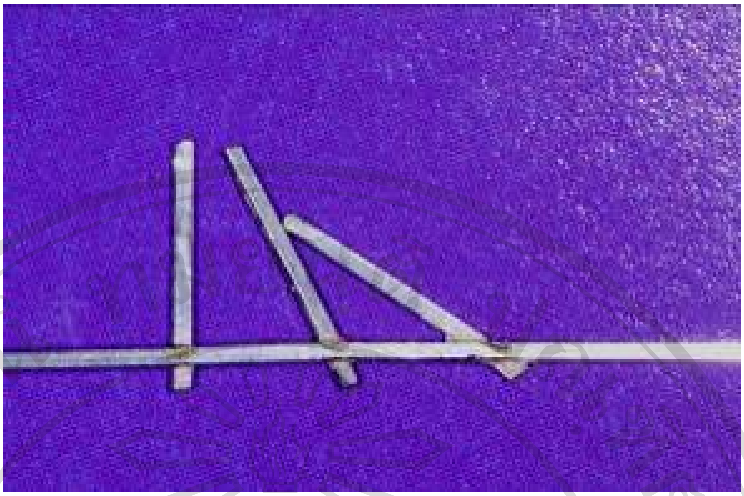

Figure 5.2 A custom-made 3-D Surgical Guide was prepared to allow precise miniscrew placement to the bone.

5.2.3 Insertion torque

For each miniscrew, maximum insertion torque (Ncm) was assessed by an Imada torque wrench (Imada Inc., Northbrook, IL) (Figure 5.3). Miniscrew implants were inserted in the bone until the head and platform were placed 1mm far from cortical bone surface (Figure 5.4). Maximum insertion torque was defined as the peak torque value during miniscrew placement.

Figure 5.3 A digital torque wrench was used to assess the maximum insertion torque during miniscrew implant placement.

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Figure 5.4 The platform of the miniscrew head was placed 1 mm from the cortical bone surface.

5.2.4 Pullout testing

To examine the pullout strength of a miniscrew inserted at an angle to the axis of the pull, a custom-made grip was designed and machined to grasp the miniscrew head, thus avoiding the bending moment created during the pullout test (Figure 5.5). The internal contours of the jaws of the grip were custom machined and had the same dimensions and profile as the screw head. A custom-made holding base was specific designed to hold the specimens (Figure 5.6). The gripping fixture was connected to the actuator of the Universal Testing Machine (Instron Corp, Norwood, MA, USA). The specimen was attached via the screw head to the grip. A crosshead speed of 0.05 mm per second (Baker *et al.*, 1999; Huja *et al.*, 2005) was applied to pullout the miniscrew implant. The peak load (Fmax) data was recorded by Bluehill software CAT No. 2603-080. Failure was defined as a rapid decline in load following the peak of force. The long axis of miniscrew implants were aligned with the axis of the testing machine as ensured that no bending moment was produced during pullout test and only axial pullout strengths was recorded.

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Figure 5.5 A custom-made base to hold the specimens and a grip to grasp the miniscrew head were specially designed to allow a controlled angle to the axis of the pull.

Figure 5.6 A custom-made grip was specifically designed to hold the head of the miniscrew.

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5.2.5 Statistical analysis

Descriptive statistics and multiple comparisons between groups were performed using one-way ANOVA and post-hoc analyses by the Tukey's test to detect any difference between pullout characteristics. The differences of maximum pullout strength and maximum insertion torque between maxilla and mandible were analyzed using a Student t-test. Pearson correlation coefficients were used to study the relationship between pullout strength and insertion torque. The results were considered significant when $p < 0.05$. All calculations were performed through the use of SPSS version 10.0 for windows (SPSS Inc., Chicago, IL, USA).

5.3) Results

Maximum pullout force and insertion torque was assessed and analyzed for miniscrew implants inserted in three different orientations relatively to the cortical bone surface of the dentoalveolar area. Relatively high correlation was observed between maximum pullout force and insertion torque ($r = 0.81$, $p < 0.01$).

Results of maximum pullout strength and maximum insertion torque measurements of miniscrews inserted in the dentoalveolar bone of maxilla and mandible are shown in the Tables 5.1 to 5.6.

In general, miniscrews inserted in the mandibular bone exhibited significant ($p < 0.05$) higher values for the maximum pullout strength and maximum insertion torque compared to the miniscrews inserted in the maxilla (Tables 5.1 and 5.2).

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Table 5.1 Maximum pullout strength values (N) of miniscrews inserted at selected angulations in maxilla and mandible.

Angulations	Maxilla		Mandible		t-test
	Mean	*SD*	*Mean*	*SD*	
30º	195.51	102.77	305.45	145.12	0.000
60º	217.36	133.81	493.47	296.73	0.000
90º	233.29	131.43	422.78	277.63	0.000

Table 5.2 Maximum insertion torque values (Ncm) of miniscrews inserted at selected angulations in maxilla and mandible.

Angulations	Maxilla		Mandible		t-test
	Mean	*SD*	*Mean*	*SD*	
30º	3.03	1.85	4.51	1.97	0.000
60º	3.14	2.15	5.34	2.92	0.000
90º	3.42	2.13	4.53	2.83	0.017

In the dentoalveolar bone of maxilla, no significant differences between the maximum pullout strength and insertion torque of miniscrews inserted with 30, 60 or 90 degrees to the bone surface was observed. The anterior area of maxilla exhibited significant lower maximum pullout and insertion torque values compare to both middle (p < 0.001) and posterior areas (p < 0.001). No significant difference was observed between the maximum insertion torque values of miniscrews inserted in the middle and posterior areas of the maxilla (Tables 5.3 and 5.4).

Table 5.3 Maximum pullout strength values (N) of miniscrews inserted at selected angulations in maxilla.

Angulations	Anterior		Middle		Posterior		Tukey's
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	
30º	94.04	38.56	241.17	86.97	251.32	86.22	Ant < Mid = Post
60º	98.04	51.73	221.32	113.91	332.72	104.56	Ant < Mid < Post
90º	126.54	51.73	231.60	89.80	334.67	139.70	Ant < Mid < Post
Tukey's	30º = 60º = 90º		30º = 60º = 90º		30º = 60º = 90º		

Ant, Anterior; Mid, Middle; Post, Posterior

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Table 5.4 Maximum insertion torque values (Ncm) of miniscrews inserted at selected angulations in maxilla.

Angulations	Anterior		Middle		Posterior		Tukey's
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	
30º	1.15	0.82	3.77	1.39	4.17	1.53	Ant < Mid = Post
60º	1.27	1.00	3.50	2.00	4.64	1.78	Ant < Mid = Post
90º	1.53	1.20	3.79	1.96	4.95	1.58	Ant < Mid = Post
Tukey's	30º = 60º = 90º		30º = 60º = 90º		30º = 60º = 90º		

Ant, Anterior; Mid, Middle; Post, Posterior

In the dentoalveolar bone of mandible, the use of insertion angulation demonstrated a significant ($p < 0.01$) effect on the maximum pullout and insertion torque values. However, these changes did not follow a unique pattern for the several areas of mandible (anterior, middle and posterior).

In the anterior area of mandible, miniscrews inserted with 30 degrees (220.04 ± 123.95 N and 3.05 ± 1.47 Ncm) (mean ± SD) to the bone surface exhibited significant higher maximum pullout and insertion torque values compared to both 60 (135.11 ± 61.93 N and 1.90 ± 1.34 Ncm) ($p < 0.05$) and 90 degrees (107.59 ± 66.27 N and 1.37 ± 1.40 N cm) ($p < 0.01$).

In contrast, in the posterior area of mandible, miniscrews inserted with 30 degrees (300.86 ± 152.70 N and 4.64 ± 1.69 Ncm) to the bone surface exhibited significant lower maximum pullout and insertion torque values compared to both 60 (629.44 ± 156.24 N and 6.96 ± 1.83 Ncm) ($p < 0.001$) and 90 degrees (692.58 ± 167.24 N and 6.92 ± 1.70 Ncm) ($p < 0.001$). In the anterior and posterior areas, no significant difference was observed between miniscrew implants inserted with 60 and 90 degrees (Tables 5.5 and 5.6).

In the middle area of mandible, miniscrews inserted with 60 degrees (715.86 ± 196.14 N and 7.16 ± 1.64 Ncm) to the bone surface exhibited significant higher maximum pullout and insertion torque values ($p < 0.05$) compared to the 30 and 90 degrees. No significant difference was observed between miniscrew implants inserted

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with 30 (395.46 ± 102.38 N and 5.12 ± 1.97 Ncm) and 90 degrees (468.17 ± 153.70 N and 5.31 ± 1.71 Ncm).

Table 5.5 Maximum pullout strength values (N) of miniscrews inserted at selected angulations in mandible.

Angulations	Anterior		Middle		Posterior		Tukey's
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	
30º	220.04	123.95	395.46	102.38	300.86	152.70	Ant < Mid = Post
60º	135.11	61.93	715.86	196.14	629.44	156.24	Ant < Mid = Post
90º	107.59	66.27	468.17	153.70	692.58	167.24	Ant < Mid < Post
Tukey's	30º > 90º = 60º		30º = 90º < 60º		30º < 90º = 60		

Ant, Anterior; Mid, Middle; Post, Posterior

Table 5.6 Maximum insertion torque values (Ncm) of miniscrews inserted at selected angulations in mandible.

Angulations	Anterior		Middle		Posterior		Tukey's
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	
30º	3.05	1.47	5.12	1.97	4.64	1.69	Ant < Mid = Post
60º	1.90	1.34	7.16	1.64	6.96	1.83	Ant < Mid = Post
90º	1.37	1.40	5.31	1.71	6.92	1.70	Ant < Mid < Post
Tukey's	30º > 90º = 60º		30º = 90º < 60º		30º < 90º = 60º		

Ant, Anterior; Mid, Middle; Post, Posterior

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5.4) Discussion

The main common justifications for orienting miniscrews in an angled direction during insertion are to increase the mechanical retention (Deguchi *et al.*, 2006), to allow use of longer screws (Liou *et al.*, 2007; Poggio *et al.*, 2006) and to avoid damage to the roots of adjacent teeth (Herman and Cope, 2005; Morea *et al.*, 2005; Poggio *et al.*, 2006). This concept has been widely recommended in the protocols for miniscrew placement in the dentoalveolar and has guided manufactures to design miniscrews for orthodontic anchorage (Deguchi *et al.*, 2006; Herman *et al.*, 2006; Jeon Y.J. *et al.*, 2006; Kravitz and Kusnoto, 2006; Kyung H.M. *et al.*, 2003; Maino *et al.*, 2005a; Park *et al.*, 2004b; 2006; Suzuki and Buranastidporn, 2005).

In the present study, the influence of miniscrews inserted in the dentoalveolar bone on the maximum pullout load and insertion torque was assessed and analyzed. To the authors' knowledge, the assessment of the mechanical retention of miniscrews placed in to the dentoalveolar bone at angulations has not been reported.

Determination of pullout strength is a standardized method of testing the mechanical competency or holding power of a screw. Therefore, the quantification of the tensile forces required to pull a screw out of a particular material determines its pullout strength (An and Draughn, 2000; Huja *et al.*, 2005).

However, several factors are associated with the mechanical retention of miniscrews to the bone, such as, miniscrew size and design (Carano *et al.*, 2005b; Heidemann *et al.*, 2001; Song *et al.*, 2007; Wilmes *et al.*, 2006), insertion technique, angle of penetration, miniscrew hole preparation method (Carmouche *et al.*, 2005; Kim *et al.*, 2005) and the particular characteristics of the recipient bone (Huja *et al.*, 2005; Huja *et al.*, 2006; Wilmes *et al.*, 2006). Therefore, each parameter must be considered carefully.

In the present study, only one type of miniscrew was selected to perform the mechanical assessment in order to eliminate variations related to the characteristics of the miniscrew. Possible variations related to the insertion technique, such as the angle of penetration and the method of miniscrew hole preparation, was controlled with the use of systematic protocol of miniscrew implant placement with the use of a 3-D surgical guide.

Since the dentoalveolar bone of maxilla and mandible present particular characteristics, such as, heterogeneous structures, different cortical bone thickness and density (Devlin *et al.*, 1998; Fanuscu and Chang, 2004; Miyamoto *et al.*, 2005; Nkenke *et al.*, 2003; Norton and Gamble, 2001), and complex arrangement of the trabeculae (Fanuscu and Chang, 2004), the direction and location of miniscrew insertion are vital parameters that must be considered, evaluated and optimized.

In this study, a relatively strong correlation was observed between maximum pullout strength and insertion torque. The results are in agreement with several articles

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describing the mechanical tests with pedicle screws used in spinal fixation devices (Carmouche *et al.*, 2005; Daftari *et al.*, 1994; Zdeblick *et al.*, 1993). In this study, independently from the adopted insertion angulation, miniscrews inserted in the mandibular bone exhibited significant improved mechanical retention compared to the miniscrews inserted in the maxilla. The main explanation for this difference is the variation of the cortical bone thickness and bone mineral density between maxillary and mandibular areas. These results are in agreement to the previous studies (Deguchi *et al.*, 2006; Devlin *et al.*, 1998; Huja *et al.*, 2005; 2006; Miyamoto *et al.*, 2005).

Maxillary bone

According to the results obtained in this study, the use of different insertion angulations for miniscrew placement in the dentoalveolar bone of maxilla did not provide improved mechanical retention of these miniscrews to the bone. These results are not in accordance to previous studies that had suggested the use of reduced angulation in order to achieve increased miniscrew/bone contact surface. However, the effects of implant insertion angle on the biomechanical performance of the miniscrew implants in the dentoalveolar bone were not evaluated (Deguchi *et al.*, 2006).

The possible explanation is the thickness and density of the cortical bone presented in the dentoalveolar bone of maxilla. Since the retention of the miniscrews in the maxilla is obtained mainly through the mechanical retention of the miniscrew in the cortical bone (Miyamoto *et al.*, 2005; Miyawaki *et al.*, 2003; Song *et al.*, 2007; Wilmes *et al.*, 2006), the relatively thin maxillary cortical bone (Deguchi *et al.*, 2006; Fanuscu and Chang, 2004; Miyamoto *et al.*, 2005; Peterson *et al.*, 2006) might not be sufficient to provide the desired increase in the screw/bone contact surface. As a consequence, the variations in the insertion angulation in the maxillary bone would not alter significantly the mechanical retention of these miniscrews. This explanation is supported by Daftari *et al.*(1994) who investigate the correlations between screw hole preparation and pullout strength by using both synthetic and calf vertebrae. They found that insertion torque correlated with pullout strength. Additionally, they found that overdrilling the pilot hole was strongly related with decreased pullout strength.

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This finding emphasized the fact that cortical purchase is of greater import than purchase attained in cancellous bone.

Another possible explanation is the frequently thinner cortical bone combined with thicker trabecular bone and a poor degree of bone mineralization presented in the posterior maxilla (Fanuscu and Chang, 2004). This low density of bone, also known as "soft bone" is often associated with deficient miniscrew's primary stability and higher miniscrews failure rates (Lazzara *et al.*, 1996). It is suggested that the insertion of miniscrews at angulation in the maxillary "soft bone" does not contribute to the enhancement of the mechanical retention of the miniscrew.

Another possible explanation is the relatively large size of the thread pitch of the available commercially miniscrew compared to the average of maxillary cortical bone thickness (0 to 2.4 mm) (Deguchi *et al.*, 2006; Fanuscu and Chang, 2004; Miyamoto *et al.*, 2005; Peterson *et al.*, 2006). In general, miniscrews present with the standard miniscrew thread of 1.0 mm, which is comparatively larger than the average thickness of the maxillary cortical bone. Miniscrews with small thread pitch would provide improved retention miniscrew retention to the bone (DeCoster *et al.*, 1990). This is a new finding obtained in this study. However, further studies are necessary to elucidate the mechanism of miniscrew retention in the maxillary bone.

Mandibular bone

In the dentoalveolar bone of mandible, although the use of different insertion angulations for miniscrew placement had significantly influenced the mechanical properties of these miniscrews, there were no similar patterns between the different insertion locations, i.e. different insertion angulation in different sites of the mandible, provided different patterns of mechanical retention.

The use of reduced insertion angulation to the cortical bone surface, such as 30 degrees, improved significantly the mechanical retention of miniscrews only in the anterior area of the mandible. In contrast, this same angulation provided the lowest values for the maximum pullout and insertion torque in the posterior area of the mandible. Moreover, for the middle portion of the mandible, no significant difference was observed between miniscrews inserted with 30 and 90 degrees.

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One possible explanation for such differences are the varied quality and quantity of cortical bone presented in the anterior and posterior portion of mandible (Deguchi *et al.*, 2006). Since the posterior area of mandible, where more compact cortical bone is presented, the use of reduced angulation might generate microcracks in the bone, therefore reducing the mechanical retention of miniscrew to the bone. Robert *et al.*(2003) assessed the effect of divergent screw placement on the initial strength of plate-to-bone fixation. They observed that the insertion of screws at angulations levers out a portion of the material (adjacent to the screw), increasing the local stresses, and furthermore propagates the fracture at the screw hole. Additionally, they observed that this type of failure was apparent with screws placed at angles of 20 degrees or lesser.

Another possible explanation is the quality and density of the cancellous bone in the mandibular bone. Comparing to the maxillary bone, the mandibular cancellous bone is more dense and compact. Since the insertion of miniscrews at angulations would result in different miniscrews penetration depths, the amount of bone purchase is decreased. Consequently the insertion of miniscrews at angulation plays an important role on the mechanical retention of miniscrew implants in the mandible.

This study is our first attempt to assess the effects of the insertion angulation on the mechanical performance of the miniscrew implants. Further studies are necessary to evaluate the mechanism of miniscrew retention in the maxillary and mandibular bones.

5.5) Conclusions

In the current literature, miniscrew insertion with reduced angulation may provide an increase miniscrew/bone contact, thus leading to increased pullout strength. However in this study, there were no statistical differences in pullout strength and maximum insertion toque between miniscrews implanted at 30, 60 or 90 degrees in the maxillary bone. Miniscrew inserted with reduced angulation (30 degrees) was only effective on the anterior portion of the mandible. The thickness and density of the cortical bone plays an important role on the mechanical retention of miniscrew implants. Further studies are necessary to evaluate the mechanism of miniscrew retention in the maxillary and mandibular bones.

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