Mechanical properties of orthodontic miniscrews depending on the vertical insertion force and cortical bone thickness

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감사의 글

이 논문이 완성되기까지 관심과 배려를 아끼지 않으시고 많은 가르침을 주신 황충주 교수님께 먼저 깊은 감사를 드립니다. 아울러 제가 이 자리에 설 수 있도록 이끌고 지도해 주신 손병화 교수님, 박영철 교수님, 백형선 교수님, 김경호 교수님, 최광철 교수님께 감사의 말씀을 전합니다. 그리고 논문에 대해서 심사 때부터 관심을 가져주시고 많은 조언을 해주신 유형석 교수님, 이기준 교수님께 진심으로 감사드립니다.

또한 실험 내용과 세부 사항에 대해 많은 도움과 조언을 해주신 차정열 선생님께도 감사의 인사를 드립니다. 격려를 해 준 동기들, 김수연, 박주영, 최낙천, 최진환, 홍재현 선생과 관심을 가지고 수고를 해 준 의국원들 특히 조선미, 임경섭 선생에게 감사의 말을 전합니다.

마지막으로 항상 부족한 저를 믿고 버팀목이 되어주시는 아버지와 사랑으로 보살펴 주시는 어머니, 옆에서 든든하게 지켜보는 형에게도 깊은 감사의 말씀을 드리며 이 자그마한 결실을 드립니다.

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This study examined the mechanical properties of a miniscrew in cortical bone with various thicknesses using different vertical forces (1260 g and 1470 g). Three types of miniscrews with different shapes (Type A: cylindrical type, Type B: partially cylindrical type, Type C: tapered type) were inserted into artificial bone blocks at various cortical bone thicknesses. The insertion and removal torque and pullout strength were measured using a torque tester with a constant rotational speed of 3 rpm. The overall maximum insertion and removable torque increased with increasing cortical bone thickness to 1.0mm and 1.5mm. A tapered shaped miniscrew is recommended when the initial stability of the miniscrew is enhanced by increasing the torque. In addition, the torque increased more when the vertical force was 1260 g instead of 1470 g, which indicates that the initial stability can be affected by the changes in the vertical force. However, more studies with various experimental methods will be needed to obtain the ideal range vertical force.

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* Key words: miniscrew, mechanical property, stability, vertical force

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Ⅰ. Introduction

In the field of orthodontics, it is essential to be able to move teeth without limitations to acquire an idealistic appearance and stabilized occlusion. In order to achieve this goal, there is a need for an absolute anchor system other than the existing concept of action and reaction. Previously, the absolute anchor for orthodontic implants was developed from prosthodontic studies[1-6]. The orthodontic mini implant was one of the outcomes of these studies. Kanomi and Costa et al reported that this type of mini implant could be removed easily, be used for many purposes and have economical advantages [7-12].

However, there is insufficient experimental data regarding the shapes and properties of the miniscrew, the interaction with the bone before and after insertion, and the influences of the thickness and density of the bone on the initial stability. Stability, which is the most important and basic factor for the predictable outcomes of orthodontic treatment, is essential for the successful applications of the miniscrew to patients.

It was suggested that there are three major factors related to the stability of the miniscrew, the host, implant, and retention factors. The host factor refers to the general health condition and local bone status. The implant factor refers to the biological and mechanical information. The retention factor is referred to as the condition of the bone-screw interface, the load applied to the miniscrew and the oral hygiene status [13]. Okuyama reported that there were other factors such as length, external diameter, shape, bone density, and elasticity of the cancellous bone that influenced the stability of the miniscrew [14]. Since various factors affect the stability of the miniscrew, it is essential to understand the biological and biomechanical roles of each factor.

One of the factors that have an effect on the stability of the miniscrew is the insertion torque, which plays an important role in the procedure for inserting the miniscrew [15,16]. Okuyama et al reported that the insertion torque of a screw, which is generated primarily by the shearing force and friction in the bone-screw interface, was defined as an angular moment of the force required to advance the screw into the bone. In addition, cadaveric studies showed that the insertion torque of a pedicle screw strongly correlated with the pull out strength [14]. However, it was suggested that measurements of the removal torque was used as a initial evaluation of the stability of the implant or miniscrew [17,18]. Song reported that there was a significant difference in the insertion and removal torque depending on the thickness of the cortical bone and the shape of the miniscrew [19]. It is easy to generate an excessive vertical force because the miniscrew penetrates into the thick cortical bone during the insertion procedure. Such a force could waver the axis of the miniscrew during the insertion procedure and damage the cortical bone. This would ultimately result in the failure of the initial stability [13]. However, it is difficult to control the extent of the vertical force and there are few reports that have examined the vertical force. Therefore, it is important to examine the initial stability of the miniscrew as a function of the vertical force.

The purpose of this study was to examine the mechanical properties of a miniscrew in cortical bone with various thicknesses using different vertical forces (1260 g and 1470 g).

Ⅱ. Materials and Methods

Drill-free type orthodontic miniscrews are classified according to the morphologic characteristics of the screw; the researcher surveyed principal measurements of each mini-screw with instrumental microscope (MF-A1010H, Mitutoyo Corp.Osaka, Japan) (Table 1, Fig 1). In this study, biomechanical test block (Sawbones®, A Division of Pacific Research Laboratories Inc., USA) that is an experimental artificial bone was used. E-glass-filled epoxy sheet and solid rigid polyurethane foam were used as an alternate experimental material of cortical bone and human cancellous bone repectively. Three types of the artificial bone samples according to the thickness of the experimental cortical bone of 0 mm, 1 mm, 1.5 mm with length 110 mm, width 10 mm, height 10 mm were devised. (table 2)

Table 1. The principal properties & dimensions of miniscrews used in this study

	Type A	Type B	Type C
Screw Design	Pure cylindrical parallel part	tapered parallel part + gradually increasing core diameter part	tapered parallel part + taper part
Corporation & Model No.	Biomaterials Korea Inc. <OAS-T1507>	Jeil Medical Corp. <16-JB-008>	Ortholution <Orlus 1E16107>
Screw Length (mm)	9.0	10.5	9.5
Body Length (mm)	7.0	8.0	7.0
Thread Length (mm)	6.0	7.0	6.0
Thread Diameter (mm)	1.45 (1.5)	1.6 (1.6)	1.6 (2.0)
Core Diameter (mm)	1.0	1.0	1.0
Taper Length (mm)	-	1.5	2.5
Surface Finish	Machined	Machined	Acid etching Sand blasting
Chemical Composition	Ti-6Al-4V	Ti-6Al-4V	Ti-6Al-4V

-The dimensions in the parentheses of Thread Diameter mean the dimensions of the screw shaft, and the dimensions of Core Diameter are the dimensions in the parallel part of the screw.

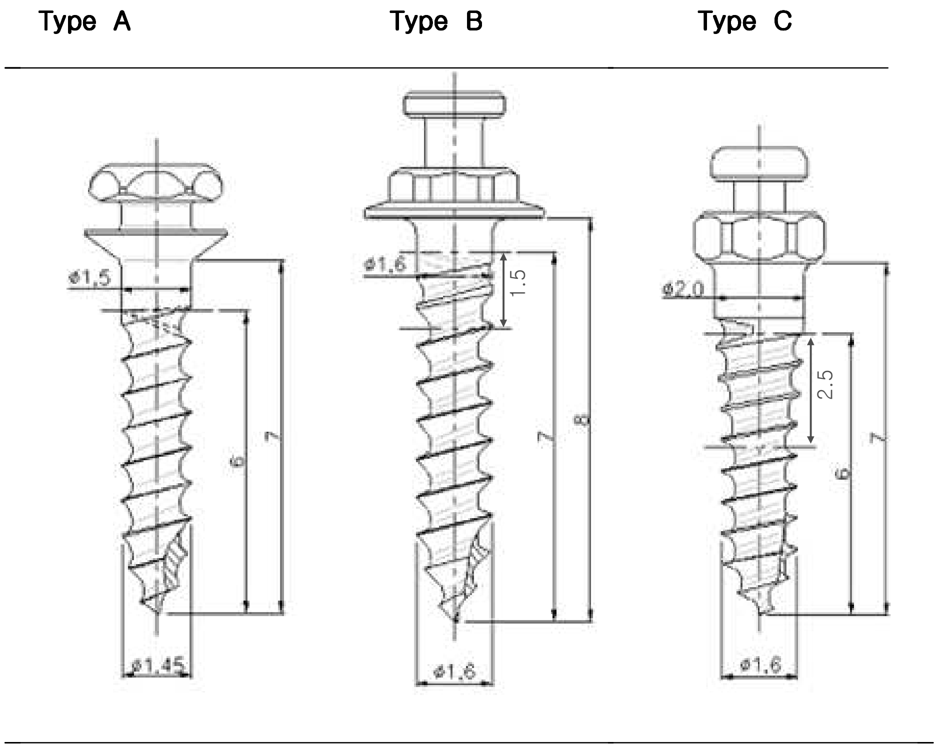


Fig 1. Schematic diagram of the miniscrews used in this study (unit;mm).

Table 2. Mechanical properties of experimental bone used in this study

Alternative Test Medium	Density (g/cc)	Compressive		Tensile	
		Strength (MPa)	Modulus (MPa)	Strength (MPa)	Modulus (MPa)
cortical bone	1.7	120	7,600	90	12,400
cancellous bone	0.80	58	1,400	32	2,000

1. Driving torque test

Using a driving torque tester (Biomaterials Korea Inc., Seoul, Korea, Fig 2) with a uniform speed of 3 rotations per minute corresponding to the regulations of the ASTM F543-02

1) Insertion torque test: The bone block was fixed on the lower part and the miniscrew was placed on the blade. The torque tester was used to insert the miniscrew until the thread portion had been fully embedded in the bone block. The torque values (N cm) could be obtained from the computer program (QuickDataAcq, SDK Developer, UK) in 0.1 sec units. The vertical forces applied to the miniscrew were 1260 g and 1470 g. The weight of the rotational axis was 1000 g and weights of 260 g and 470 g were used. Thirty mini screws of each type were used in the study. Ten mini screws each were inserted into artificial bone blocks with different cortical bone thickness, 0 mm, 1.0 mm,1.5 mm. When the miniscrews were removed from the bone block, five miniscrews were used for the removal torque test and the other five were used for the pullout strength test .The miniscrews were used only once.

2) Removal torque test : After the weight was removed, the weight of the rotational axis, 1000 g, was applied to the miniscrew. The torque tester was used to obtain the removal torque in 0.1 sec units.

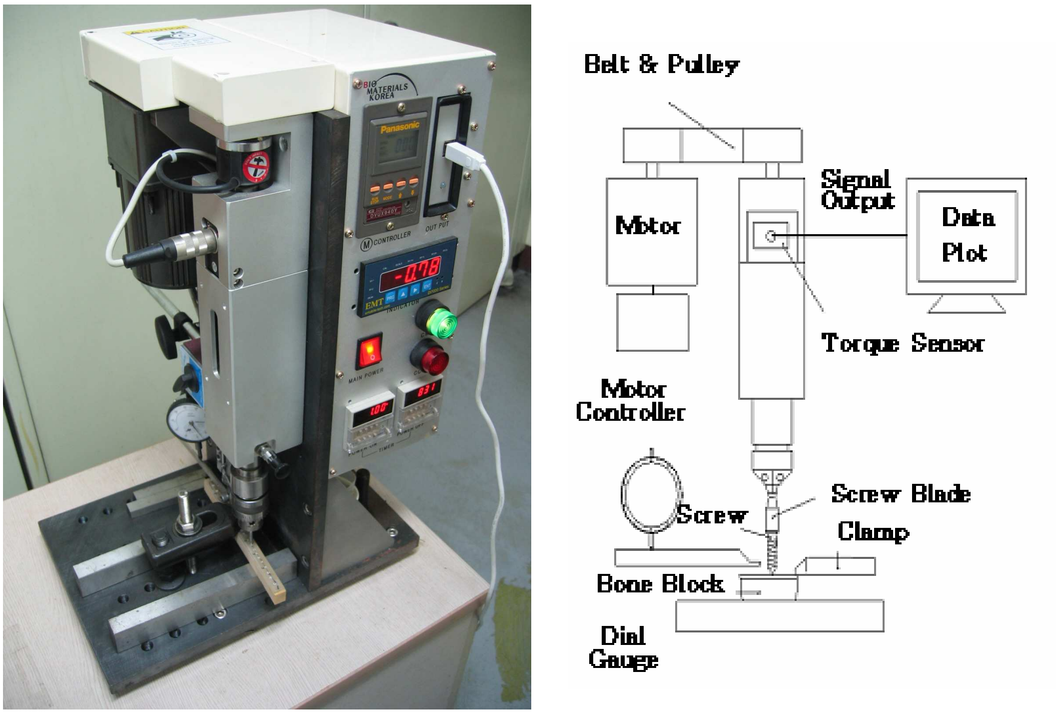


Fig 2. Photo image and schematic diagram of torque tester.
(Biomaterials Korea Inc. Seoul, Korea)

3) Pullout strength test (Fig 3): The miniscrew was inserted into the bone block up to the screw thread. This bone block was installed in the Instron and the tensile load was increased at a speed of 5 mm/min until the miniscrew had been fully removed.

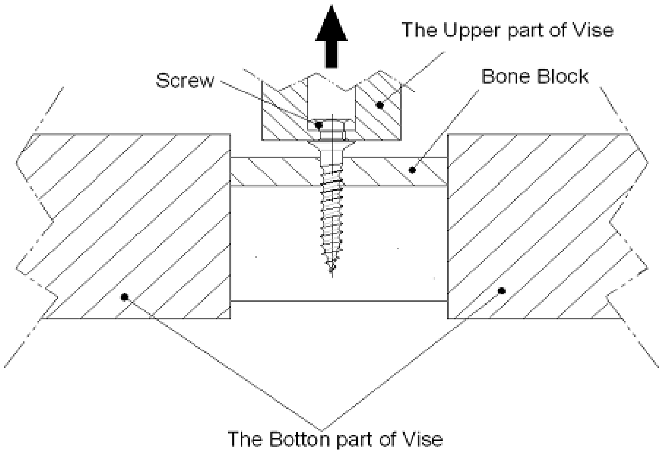


Fig 3. Schematic diagram of pullout strength test.

2. Measurement Values

1) Cortical bone insertion time (CBIT), sec.

The time taken for a tip of the miniscrew to penetrate into the cortical bone and begin to go into the cancellous bone.

2) Maximum insertion torque (MIT), N cm.

The maximum torque value, which can be obtained from the insertion till the end, among the torque values acquired to insert the miniscrew to the miniscrew thread.

3) Maximum removal torque (MRT), N cm

The maximum torque value which can be illustrated in a graph using the torque value obtained from the removing of the miniscrew.

4) Torque loss (TL), N cm

The difference between the maximum insertion torque and the maximum removal torque.

5) Pullout strength (POS), MPa

The maximum tensile load in the force-displacement graph illustrated from the pullout strength test.

The measurements listed below were taken statistically in three-way ANOVA to recognize the significances in the variables according to each type of screw, cortical bone thickness and vertical force. Turkey's studentized range test was used to authorize the order.

Ⅲ. Results

1) Cortical bone insertion time (CBIT) (Table 3, Fig 4)

The CBIT means the time taken for a tip of the miniscrew to penetrate into the cortical bone and begin to contact the interface of the cancellous bone. As a result, each type of miniscrew required a longer time to penetrate the cortical bone as the CBT became thicker.

Of the types of CBT, Type B had the shortest insertion time. The insertion time of Type A and B decreased remarkably due to the increased VF from 1260 g to 1470 g. Type C showed some variations according to the CBT.

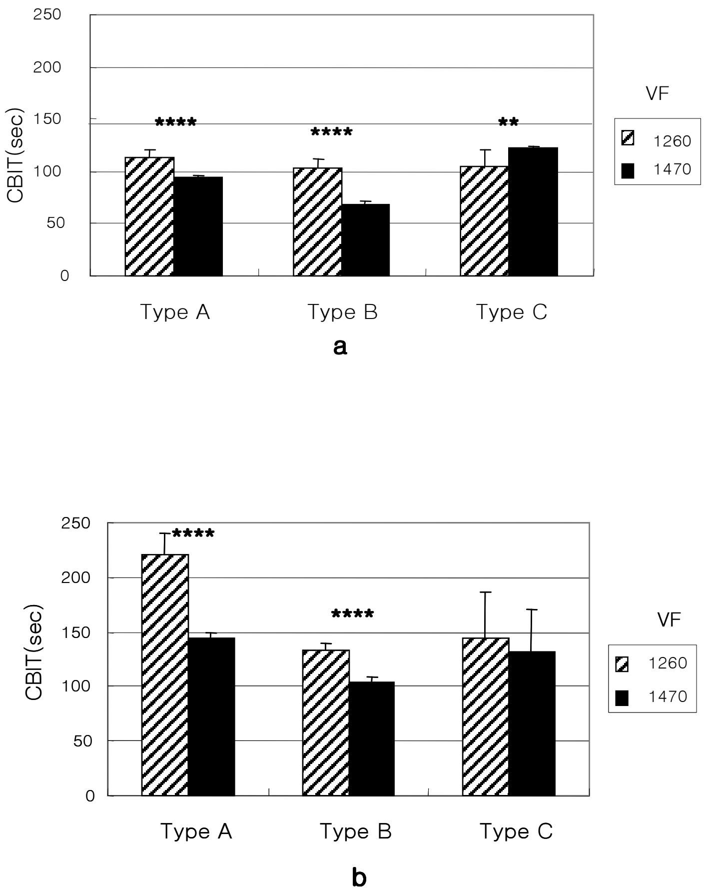


Fig 4. The mean & standard deviation of CBIT according to the vertical force, as the CBT was 1.0mm (a) and 1.5mm (b). CBIT, Cortical Bone Insertion Time, CBT, Cortical Bone Thickness, VF, Vertical Force, * P<0.05; ** P<0.01; ***P<0.001; **** P<0.0001.

Table 3. The mean & standard deviation of cortical bone insertion time(CBIT) according to the vertical force(VF) and cortical bone thickness(CBT)

(sec)

CBIT						
CBT	1 mm			1.5 mm		
TYPE/VF	1260 g	1470 g		1260 g	1470 g	
	Mean±SD	Mean±SD	sig	Mean±SD	Mean±SD	sig
Type A	113.8±6.1	94±1.6	****	221.4±18.6	144.7±5.0	****
Type B	102.8±8.5	68.7±2.2	****	132.9±7.5	103.3±5.1	****
Type C	104.1±15.7	122.1±1.2	**	145±41.2	132±38.1	NS
Tukey's	Type B<C=A			Type B<C<A		

SD, Standard Deviation, sig, significance;NS, non-significant, * P<0.05; ** P<0.01; *** P<0.001; **** P<0.0001, Tukey's, Tukey's Studentized Range Test, P <0.05.

2) Maximum insertion torque(MIT) (Table 4, Fig 5)

As a result of measuring the MIT, which was the highest torque value taken during the insertion procedure, it was shown that every type of miniscrew had a maximum torque value at the final moment of insertion. However, there were some remarkable differences depending on the cortical bone thickness. Overall, highest MIT value with every type of CBT was observed in the order of Type C> Type B>Type A. The MIT value generally decreased with increasing VF from 1260 g to 1470 g.

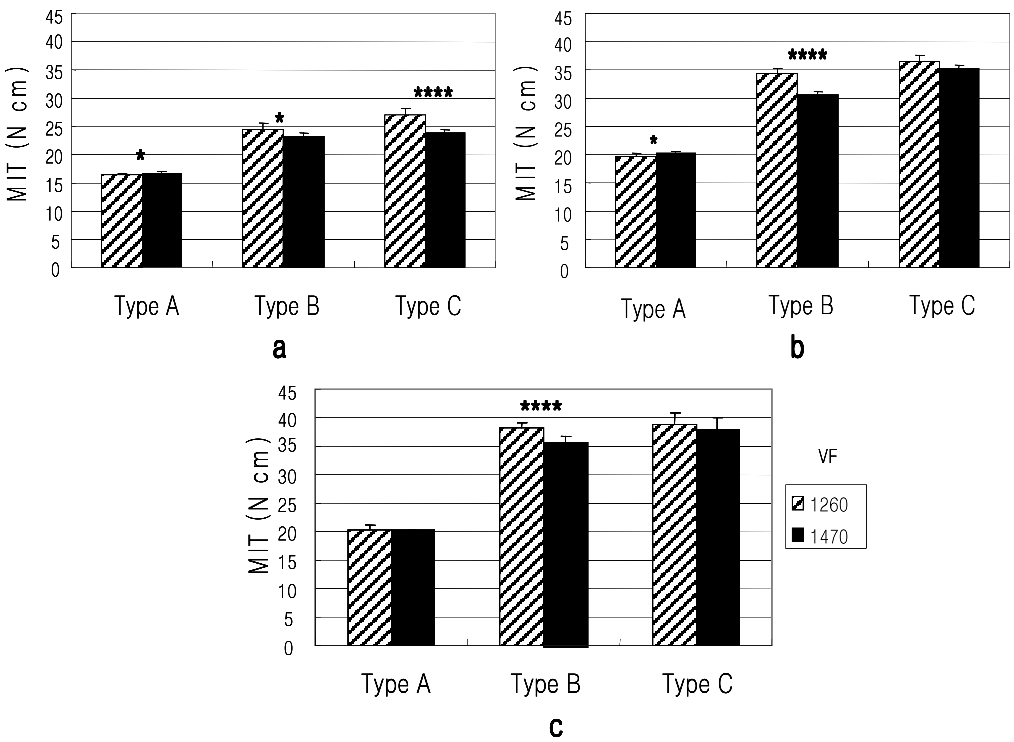


Fig 5. The mean & standard deviation of MIT according to the vertical force, as the CBT was 0mm(a), 1.0mm(b), 1.5mm(c). MIT, Maximum Insertion Torque, CBT, Cortical Bone Thickness, VF, Vertical Force, * P<0.05; ** P<0.01; *** P<0.001; **** P<0.0001.

Table 4. The mean & standard deviation of maximum insertion torque (MIT) according to the vertical force (VF) and cortical bone thickness(CBT) (N cm)

MIT									
CBT	0 mm			1 mm			1.5 mm		
TYPE/VF	1260 g	1470 g		1260 g	1470 g		1260 g	1470 g	
	Mean±SD	Mean±SD	sig	Mean±SD	Mean±SD	sig	Mean±SD	Mean±SD	sig
Type A	16.5±0.3	16.9±0.3	*	19.6±0.6	20.2±0.4	*	20.4±0.6	20.3±0.1	NS
Type B	24.4±1.2	23.3±0.6	*	34.4±1.0	30.5±0.6	****	38.3±0.7	35.8±0.8	****
Type C	27.1±1.3	24.0±0.4	****	36.4±1.4	35.4±0.4	NS	38.8±2.2	37.9±2.3	NS
Tukey's	Type A<B<C			Type A<B<C			Type A<B<C		

SD, Standard Deviation, sig, significance; NS, non-significant, * P<0.05; ** P<0.01; *** P<0.001; **** P<0.0001, Tukey's, Tukey's Studentized Range Test, P <0.05.

3) Maximum removal torque (MRT) (Table 5, Fig 6)

After the insertion torque test, the MRT, which is the highest removal torque value measured during the removal torque test, was determined. The MRT was generally higher when the CBT increased and the VF was 1260 g.

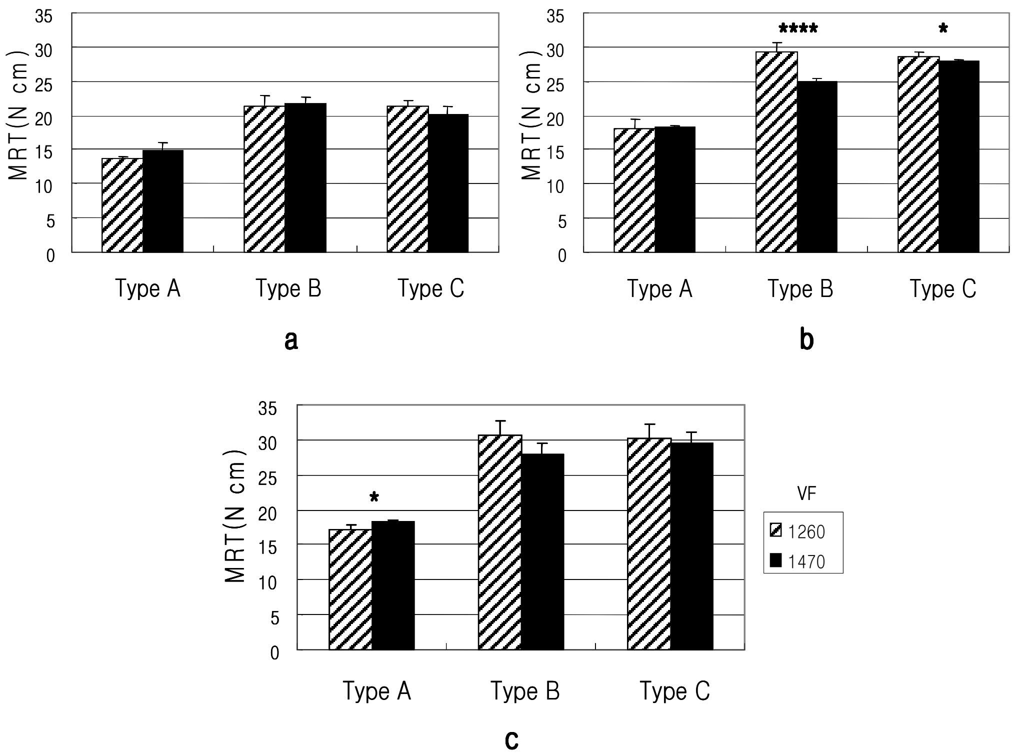


Fig 6. The mean & standard deviation of MRT according to the vertical force, as the CBT was 0mm(a), 1.0mm(b), 1.5mm(c). MRT, Maximum Removable Torque, CBT, Cortical Bone Thickness, VF, Vertical Force, * P<0.05; ** P<0.01; *** P<0.001; **** P<0.0001.

Table 5. The mean & standard deviation of maximum removable torque(MRT) according to the vertical force(VF) and cortical bone thickness(CBT)

(N cm)

	MRT								
CBT	0 mm			1 mm			1.5 mm		
TYPE/VF	1260 g	1470 g		1260 g	1470 g		1260 g	1470 g	
	Mean±SD	Mean±SD	sig	Mean±SD	Mean±SD	sig	Mean±SD	Mean±SD	sig
Type A	13.7±0.2	14.9±1.0	NS	18.1±1.4	18.2±0.3	NS	17.1±0.8	18.3±0.2	*
Type B	21.3±1.6	21.7±1.0	NS	29.4±1.3	24.9±0.5	****	30.6±2.2	27.8±1.7	NS
Type C	21.3±0.7	20.1±1.1	NS	28.7±0.5	28.0±0.1	*	30.1±2.2	29.5±1.7	NS
Tukey's	Type A<C=B			Type A<B<C			Type A<C=B		

SD, Standard Deviation, sig, significance; NS, non-significant, * $P<0.05$; ** $P<0.01$; *** $P<0.001$; **** $P<0.0001$, Tukey's, Tukey's Studentized Range Test, $P <0.05$.

4) Torque loss (TL) (Table 6, Fig 7)

The MRT increased with increasing MIT. However, the TL, which was the difference between the MRT and MIT, also increased. Type A had the lowest TL compared with Types B and C.

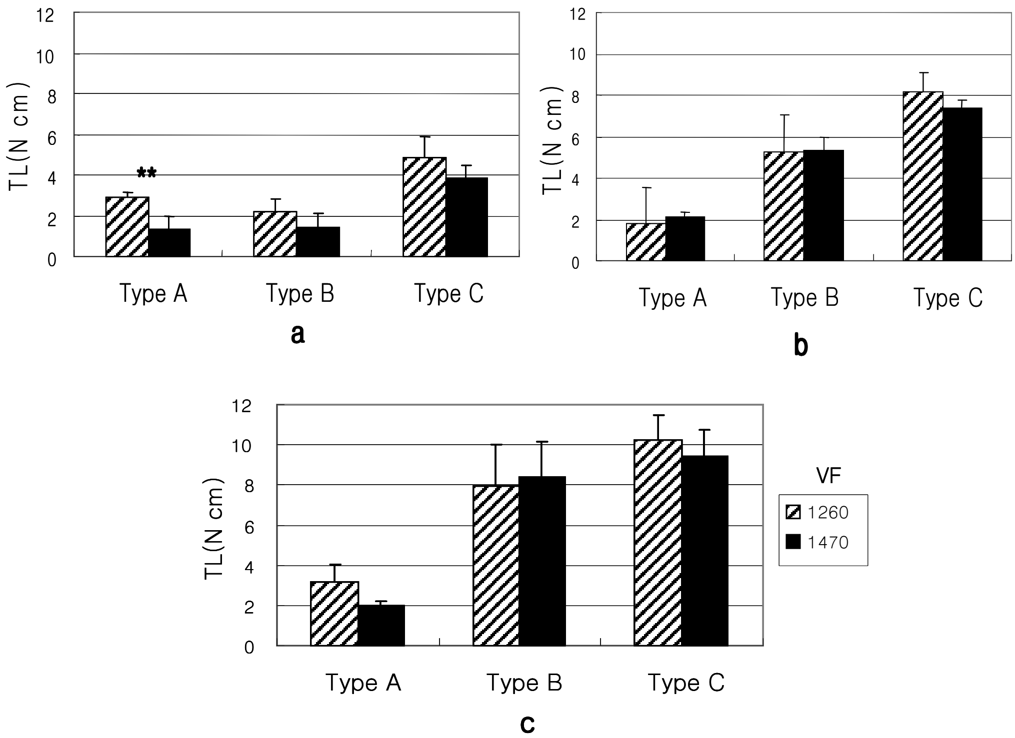


Fig 7. The mean & standard deviation of TL according to the vertical force, as the CBT was 0mm(a), 1.0mm(b), 1.5mm(c). TL, Torque Loss, CBT, Cortical Bone Thickness, VF, Vertical Force, * $P<0.05$; ** $P<0.01$; *** $P<0.001$; **** $P<0.0001$.

Table 6. The mean & standard deviation of torque loss(TL) according to the vertical force(VF)

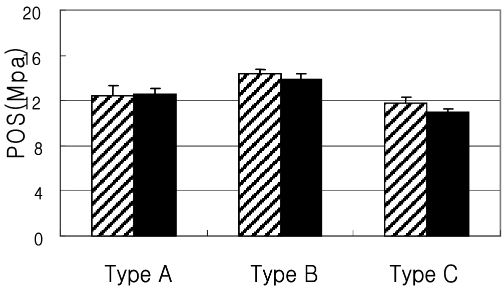
(N cm)

TL									
CBT	0 mm			1 mm			1.5 mm		
TYPE/VF	1260 g	1470 g		1260 g	1470 g		1260 g	1470 g	
	Mean±SD	Mean±SD	sig	Mean±SD	Mean±SD	sig	Mean±SD	Mean±SD	sig
Type A	2.9±0.2	1.4±0.7	**	1.8±1.7	2.1±0.2	NS	3.1±0.9	2.0±0.2	*
Type B	2.2±0.6	1.4±0.7	NS	5.2±1.8	5.4±0.6	NS	8.0±2	8.4±1.8	NS
Type C	4.9±1.0	3.8±0.7	NS	8.2±0.9	7.4±0.3	NS	10.2±1.3	9.4±1.3	NS
Tukey's	Type B=A<C			Type A<B<C			Type A<C=B		

SD, Standard Deviation, sig, significance; NS, non-significant, * P<0.05; ** P<0.01; *** P<0.001; **** P<0.0001, Tukey's, Tukey's Studentized Range Test, P <0.05.

5**) Pullout strength (POS) (Table 7, Fig 8)**

The POS of Type C was smaller than that of Types A and B with every CBT. Each type of mini-screw showed a slight increase in the POS with increasing CBT. On the other hand, there was little correlation between the POS and the changes in the VF.



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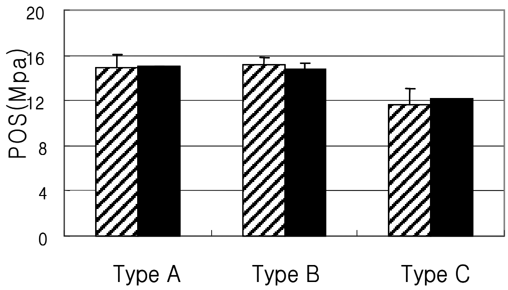

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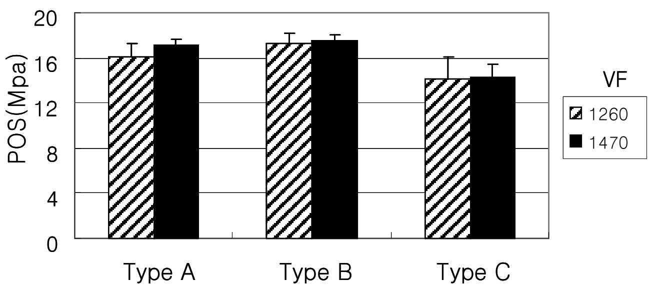

c

Fig 8. The mean & standard deviation of POS according to the vertical force, as the CBT was 0mm (a), 1.0mm(b), 1.5mm(c). POS, Pullout strength, CBT, Cortical Bone Thickness, VF, Vertical Force.

Table 7. The mean & standard deviation of pullout strength(POS) according to the vertical force (VF) and cortical born thickness(CBT)

(Mpa)

POS									
CBT	0 mm			1 mm			1.5 mm		
TYPE/VF	1260 g	1470 g		1260 g	1470 g		1260 g	1470 g	
	Mean±SD	Mean±SD	sig	Mean±SD	Mean±SD	sig	Mean±SD	Mean±SD	sig
Type A	12.5±0.8	12.5±0.6	NS	14.9±1.2	15.0±0.4	NS	16.1±1.1	17.1±0.5	NS
Type B	14.4±0.4	13.9±0.5	NS	15.1±0.7	14.8±0.5	NS	17.2±1	17.5±0.6	NS
Type C	11.7±0.6	11.0±0.2	NS	11.7±1.4	12.1±0.1	NS	14.1±2	14.2±1.2	NS
Tukey's	TypeC<A<B			Type C<B=A			Type C<B=A		

SD, Standard Deviation, sig, significance; NS, non-significant, * P<0.05; ** P<0.01; *** P<0.001; **** P<0.0001, Tukey's, Tukey's Studentized Range Test, P <0.05.

Ⅳ. Discussion

It is important to acknowledge the changes in the insertion and removal torque at different VF even though it is difficult to control the VF clinically. Another variable used in this study other than the VF was the CBT. It was reported that the cortical bone thickness varied in the different sites of jaw bones [20].

The CBIT was measured in order to determine how fast the orthodontic miniscrew could penetrate the cortical bone easily. Among the three types of the miniscrews, Type A had the lowest MIT and the highest CBIT value. Regarding the effect of the VF according to the CBIT, a shorter CBIT was observed with a

VF of 1470g than with 1260g in the same CBT. Furthermore the CBIT in every miniscrew type increased with increasing CBT.

When the CBT was increased from 1.0mm to 1.5mm, overall the MIT showed a tendency to increase. However, the MIT decreased with increasing VF from 1260g to 1470g. This might be due to the lower stress distribution around the part of the miniscrew penetrating the cortical bone due to the concentration of stress around the tip of the miniscrew with increasing VF. Nevertheless, this result requires more study using finite element analysis. Since the shape of Type A, with the exception of the tip part, was formed with the parallel part, it had a relatively lower MIT value compared with other types of miniscrew. Mann et al reported that a non-tapered screw would have a lower insertion torque and pull-out strength due to the wedging action of the tapered screw [21]. In addition, the fact that Type A had the smallest diameter, 1.45mm, might also be a factor.

Baik reported that in three-dimensional finite element analysis of the orthodontic miniscrew, the stress could be changed in the greatest amount by changing the diameter of the miniscrew. Hence, increasing the diameter of the miniscrew with increasing orthodontic force was beneficial to the stress distribution [22]. Type B was a partial cylindrical shape with a part whose inner diameter that decreases progressively towards the tip. Type C was a mixed shape with both a parallel and tapered part. When inserted through the cortical bone, the lateral pressure, which was generated in the contact areas with the cortical bone, increased due to the tapered part of the miniscrew. O'Sullivan reported that the taper designed implant had a higher initial stability than the standard implant design [23]. In addition, it was reported that the tapered shaped miniscrew had a higher insertion and removal torque than the cylindrical shape [24]. Hence, a taper shaped miniscrew may be beneficial for the initial stability. In this study, the tapered shaped miniscrew had a higher MIT and MRT than the pure cylindrical shape.

In the MRT, Type A did not change significantly with the changes in the VF. Probably, the fact that Type A had the smallest diameter, 1.45mm, might also be a factor. The MRT decreased in Types B and C with increasing VF. This might be due to the lower stress distribution around the part of the miniscrew similar to the MIT. In addition, the MRT values, like the MIT, had a tendency to increase gradually according to the CBT.

In every type of screw, the removal torque was less than the insertion torque. This suggests that the torque measured at the moment of insertion was not preserved. This means that there was some TL. When the miniscrew was inserted to the end of the miniscrew head by a rotational force, the torque was inceased to the highest value at the terminal stage of insertion. However, the remaining stress of the miniscrew decreased slightly with the removal of the rotational force. The equilibrium of force between the miniscrew and material might have been maintained when the miniscrew was inserted.

Types B and C with a greater MIT than Type A, had a greater MRT as well. In addition, Type A had the smallest TL and Type C had the largest, which was the result of differences in the miniscrew design. Nevertheless it is important to acknowledge the absolute numeric values. The MIT and MRT of Types B and C were higher than those of Type A despite the larger TL observed. There was no significant change in the TL with the VF. The TL, as well as the MIT and MRT showed a tendency to increase with increasing CBT.

Regarding the POS, there was no significant difference between the miniscrew types according to the VF. In this study, the POS of each type of miniscrew tended to increase with increasing CBT. However, because there were many numeric values within the error ranges, there was no significant correlation between the POS and CBT. Okuyama et al reported that the insertion torque had a strong correlation with the POS and bone density in the pedicle-screw study [14]. Huja et al reported that the CBT and POS had a weak correlation (r=0.39), and factors such as the mineral bone density and bone quality may have had an influence [25]. However, Reitman et al proposed that the POS in a screw used in the cervical vertebrae correlated with the bone density but had a weaker correlation with the insertion torque [26]. It was suggested that the insertion torque and POS showed no significant changes compared with the typical cylindrical type, particularly with the conical type of screw [27]. Consequently, the correlation between the insertion torque and POS has not yet been established. Therefore, more studies will be needed to determine this correlation.

In this study, the taper shaped miniscrew was the type of the miniscrew that could increase the torque the most. In addition, a higher torque could be obtained using this miniscrew when it was inserted into the thin cortical bone area clinically. A higher torque was acquired with a lower VF of 1260g rather than with 1470g. Although it is difficult to measure the VF level clinically, it is essential to verify the range of VF that is suitable for implantation. It is likely that there would be definite differences between the artificial bones used in this study and the actual human bone. Therefore, more studies considering this factor are needed. Furthermore, more meaningful results will be obtained if more CBT and VF values are examined.

Ⅴ. Conclusion

1. The VF increased with decreasing CBT, and the tendency of the CBIT generally decreased.
2. A higher MIT and MRT were generally obtained with increasing CBT from 1.0 to 1.5mm with a VF of 1260g rather than 1470g, except Type A.
3. The MIT and MRT were in the order of Type C > Type B > Type A for every type of CBT.
4. The amount of TL was greater with the lower VF. There was no significant difference between the POS and VF.

The tapered shaped miniscrew is recommended when the initial stability of the miniscrew is intended to be enhanced by increasing the torque values, especially in the thin cortical bone area. The torque values increased more when the vertical force was 1260g than 1470g, implicating initial stability could be affected by the changes of vertical force. However, in order to obtain this ideal vertical force range, more studies with various experimental methods are required.

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국문요약

수직 삽입력과 피질골 두께 변화에 따른 교정용 미니스크류의 기계적인 성질

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본 연구에서는 교정용 미니스크류가 그 형태와 수직력, 피질골의 두께에 따라서 기계적인 성질이 어떻게 변화하는지를 측정, 고찰하였다.

피질골의 두께를 달리한 인공골 시편에 두 종류의 수직력을 가하여 서로 다른 디자인의 self-tapping 교정용 미니스크류(Type A; 순수한 cylindrical 형태, Type B; taper 형태, Type C; taper 형태)를 식립하였다. 회전속도가 3rpm으로 일정한 토오크 테스터를 사용하여 삽입, 제거 토오크 및 이 때 걸린 시간, 그리고 pull out strength를 측정하여 다음과 같은 결론을 얻었다.

1. 피질골 두께가 감소하고 수직력이 1470 g 일 때에, 피질골 삽입시간은 일반적으로 감소하는 경향을 보였다.

2. 수직력이 1470 g 보다 1260 g 일 때, 피질골의 두께가 1.0, 1.5mm로 증가함에 따라 최대 삽입, 제거 토오크 값이 Type A를 제외하고 전반적으로 더 높아지는 수치를 보였다.

3. 피질골 두께가 증가함에 따라 최대삽입 토오크와 최대제거 토오크의 값이 Type A의 경우 큰 차이가 나지 않는 반면 Type B, C 는 유의성 있는 증가에

따르는 차이를 보였다. 결과적으로 모든 피질골 두께에서 최대삽입, 제거 토오크 값은 Type C> Type B>Type A 순으로 나타났다.

4. 수직력을 작게 주었을 때가 전체적으로 토오크 소실양이 더 많았으며, pull out strength 와 수직력 간에는 유의할 만한 관계를 보이지 않았다.

본 연구를 통해서 미니스크류의 디자인과 피질골의 두께, 수직력의 크기에 따른 삽입, 제거 토오크의 변화를 알 수 있었다. 결과적으로 토오크 값을 증가시켜 스크류 식립 후의 안정성을 증가시키려면, tapered 형태의 미니스크류를 사용하는 것이 바람직함을 알 수 있다. 이 실험에서 수직력을 1470 g보다 1260 g을 주었을 때 토오크 값이 더 증가되었으나, 이상적인 수직력의 범위를 알기 위해서는 더 다양한 실험이 필요할 것 같다.