2020년 2월

박사학위논문

CBCT analysis of anatomic structure of maxillary molar for endodontic microsurgery

-CBCT를 이용한 상악 대구치 부위의 치근단 수술을 위한 해부학적 구조 분석-

조선대학교 대학원

치의학과

박 보 경

2020년 2월 박사학위논문 CBCT analysis of anatomic structure of maxillary molar for endodontic microsurgery 박보경

조선대학교
CHOSUN UNIVERSITY

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지도교수 황 호 길

이 논문을 치의학 박사학위 신청 논문으로 제출함

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박보경의 박사학위논문을 인준함

위원장	연세대학교 교수	신 수 정	(인)
위 원	조선대학교 교수	김 진 수	(인)
위 원	조선대학교 교수	민 정 범	(인)
위 원	조선대학교 교수	조 형 훈	(인)
위 원	조선대학교 교수	황 호 길	(인)

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조선대학교 대학원

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국 문 초 록

CBCT를 이용한 상악 대구치 부위의 치근단 수술을 위한 해부학적 구조 분석

박 보 경
지도교수 황호길
조선대학교 대학원
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이 연구의 목적은 Cone-beam Computed Tomography(CBCT)를 이용하여 상악 대구치 치근과 피질골 표면과의 거리를 측정하고 상악 대구치 치근단과 상악동저의 위치관계 및 근접성을 평가하여 상악 대구치 부위 치근단 수술시 고려해야하는 해부학적 구조물에 대한 정보를 얻고자 하는 것이다.

사랑니 발치를 위해 내원한 한국인 환자 100명로부터 촬영된 CBCT 영상을 이용하여 각 200개의 상악 1,2 대구치와 주변 해부학적 구조물과의 관계를 평가하였다.

3mm 절단된 치근 단면의 협설 방향 너비는 상악 제1대구치 근심협측 치근(4.81mm)에서 가장 길었고 상악 제1대구치 구개측 치근(3.00mm)에서 가장 짧았다. 치근단으로부터 협측 골 두께는 상악 제2대구치 근심협측 치근(6.53mm)에서 가장 두꺼웠고 상악 제1대구치 원심협측 치근(4.55mm)에서 가장 얇았다. 3mm 절단된 치근으로부터 협측 골 두께는 상악 제2대구치 근심협측 치근(4.08mm)에서 가장 두꺼웠고 상악 제1대구치 근심협측 치근(2.43mm)에서 가장 얇았다. 치근단으로부터 구개측 골 두께는 상악 제1대구치(4.01mm)가 상악 제2대구치(3.39mm)보다 두꺼웠다. 3mm 절단된 치근으로부터 구개측 골 두께는 상악 제1대구치(2.08mm)와 제2대구치(2.03mm) 사이에서 유의한 차이가 없었다. 구개측 치은 표면에서의 직선과 치근 장축과의 각도는 상악 제1대구치(33.66°)와 제2대구치(33.98°) 사이에서 유의한 차이가 없었다. 상악 제2대구치의 치근단과 절단 3mm에서 연조직 두께

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(6.73mm,4.04mm)가 상악 제1대구치(5.28mm,3.27mm)보다 더 두꺼웠다. 근심협측, 원심협측 치근의 경우 상악동저가 치근단보다 하방에 있는 그룹의 빈도가 상악 제2대구치(37%,32.5%)가 상악 제1대구치(28%,25.5%)보다 높았다. 구개측 치근의 경우 이러한 그룹의 빈도가 상악 제1대구치(20%)가 상악 제2대구치(6%)보다 높았다.

상악 대구치 치근으로부터 피질골 표면과의 거리, 3mm 절단된 치근 단면의 협설 방향 너비, 상악 대구치 치근단과 상악동저의 위치관계는 치근의 종류와 성별에 따라 달랐다. 이 연구에서는 상악 대구치 구개측 치은 표면에서의 직선과 치근 장축과의 각도와 상악대구치 치근단과 절단 3mm에서 연조직 두께에 대해서 처음으로 평가했다. 상악 대구치 구개측 치근의 치근단 절제술을 위해 구개측 접근을 시도할 경우, 구개측 치근과 주변 해부학적 구조물간의 평가를 통해 적절한 적응증을 확인하는 것이 필요하다. 하지만 구개측 접근은 매우 어려운 치료로 상악 대구치 구개측 치근의 비외과적인 치료시 세심하고 주의 깊은 치료가 필요할 것이다.

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Ⅰ. Introduction

The objectives of root canal treatment are removal of the pathologic pulp, cleaning and shaping of the root canal system and three dimensional obturation to prevent reinfection.[1] If pulp is infected because of severe caries or other reasons, the first treatment option is non-surgical root canal treatment. And such a non-surgical root canal treatment is reported to have a high success rate. Recent studies have reported a high success rate of non-surgical root canal treatment, about 86-89%.[2,3] When the lesion of the tooth does not heal with non-surgical root canal treatment, surgical root canal treatment should be considered.[4]

Surgical root canal treatment includes endodontic microsurgery and intentional replantation. Due to the development of cone-beam computed tomography (CBCT), microscopes, instruments and materials, traditional root-end surgery has developed into endodontic microsurgery. Endodontic microsurgery is the most recent step in the evolution of periradicular surgery, applying not only modern ultrasonic preparation and filling materials but also incorporating microsurgical instruments, high-power magnification and illumination.[5] The probability of success for endodontic mircosurgery was 1.58 times the probability of success for traditional root-end surgery.[6]

For successful endodontic microsurgery, knowledge of the 3-dimensional root canal system and anatomic diversity is imperative.[7-10] Anatomical indices that should be considered for endodontic microsurgery include the thickness of surrounding bone, the dimensions and inclinations of roots, nerve, and maxillary sinus floor.[11]

CBCT can be used to analysis the anatomic structures of the surgical site. Anatomic evaluations using CBCT can provide guidance for accessing the root apex.[12-14] Access and visualization to the root apex is one of the most difficult aspects of endodontic microsurgery.[15] If there is a sound

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cortical bone, the measurement of the tooth length by using digital radiograph or even better by using CBCT can give us a precise estimation of the root apex position.[16]

There are many anatomical difficulties in case of endodontic microsurgery for the maxillary molar. The deep position of the maxillary molar in the oral cavity makes it difficult to access the instrument and secure vision. Also, due to the location of the maxillary sinus floor, it is often difficult to access the root apex. In some cases, maxillary sinus elevation may be required.

When attempting buccal approach for palatal root access, the following limitations exist. First, buccal approach would entail a significant amount of bone removal.[17] Secondly, If the maxillary sinus floor is located below the root apex, maxillary sinus elevation may be necessary. Third, palatal root may not be accessible without removing the buccal root. Because of these reasons, endodontic microsurgery for palatal root requires a palatal approach.

But there are technical difficulties existed in the palatal approach too.[18] First, the palatal approach is difficult to obtain a direct view like the buccal approach because of a shallow palatal vault or a limited jaw opening. Second, anatomical structures, such as the greater palatine vessels and nerve, make flap management difficult. Third, depending on the shape and thickness of the palatal bone, the amount of bone loss may be too high or the instrument is inaccessible. Fourth, the palatal soft tissue is much thicker and less elastic than the buccal mucosa and has a more tenacious fibrous attachment to the palatal alveolar bone, which increases the difficulty of flap management. When the palatal approach is not possible, intentional replantation is last treatment option, but it has high risk to be fractured during extraction, especially in divergent multi-rooted maxillary molars.

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The purpose of this study was to obtain information about the anatomical structures to be considered in the endodontic microsurgery of the maxillary molars by measuring the distance between maxillary molar root and cortical bone surface and evaluating the positional relationship between maxillary molar root apex and maxillary sinus floor using CBCT.

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II. Materials and methods

Sample Selection

The study sample were selected randomly from the patients visited from January 2017 to March 2017 at Chosun University Dental Hospital in Gwangju, Korea. The selected patients were taken CBCT examination to evaluate impacted third molars. Patients who had normally erupted bilateral maxillary first and second molars with three roots were selected. Severe alveolar bone loss, C-shaped molars, one or two fused roots, immature permanent molars were excluded from this study.

Coronal CBCT images of 400 teeth (200 maxillary first molars, 200 maxillary second molars) were selected to evaluate measurements from 100 Korean patients. The subjects were 51 males and 49 females, whose ages ranged from 18 to 56 years (average age:25.91 years old).

Radiographic Evaluation

CBCT images were created using the Kodak CS 9300 (Carestream Health, Rochester, NY, USA) by taking a series of 1 mm-thick cross-sectional slice images under a high-resolution with 14.5 x 16 cm field of view (FOV) and 0.2mm voxel size at 4 mA and 85 kVp. The tomographic sections were analyzed using OnDemand3D software (Cybermed, Seoul, Korea). For constant measurement, the long axis of the root was set by a straight line connecting the root apex and the center of the root-3mm below from the root apex and the modified coronal plane was set by reconstructing the long axis of the root and the occlusal plane to be perpendicular.

Relationship Between Maxillary Molar Root and Alveolar Bone

When the root tip was located at the top of the series of coronal CBCT images, this root tip was set as the root apex (Figure 1-A,C).

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The long axis of the root was set with a straight line connecting the root apex and the center of the root-3mm below from the root apex and long axis of buccal and palatal roots starting from the root apex was drawn. From the root apex, a line perpendicular to the long axis of the root was drawn. In mesiobuccal and distobuccal root, the thickness of the alveolar bone from root apex to the outer surface of the buccal cortical bone was measured (Figure 1-a). In palatal root, the thickness of the alveolar bone from root apex to the outer surface of the palatal cortical bone was measured (Figure 1-d). Assuming that the root is resected 3mm during the endodontic microsurgery, B point in buccal root and D point in palatal root were set 3mm below the root apex (Figure 1-B,D). At this point, a straight line perpendicular to the root axis was drawn. Assuming that 3mm root was resected from the root apex during endodontic microsurgery, the thickness of the alveolar bone from resected root surfaces to the outer surface of the buccal (Figure 1-b) or palatal (Figure 1-f) cortical bone was measured. Buccolingual width of resected root section was also measured (Figure 1-c,e).

Relationship Between Palatal Gingiva and Palatal Root

At points C and D, a straight line perpendicular to the root axis was drawn. The point where this straight line meets the soft tissue surface was set to E and F. And soft tissue thicknesses were measured at the root apex and 3mm resected root (Figure 1-g,h). The angle between the straight line connecting E and F and the palatal root axis was measured (Figure 1-i).

Vertical Relationship Between Maxillary Molar Root Apex and The Maxillary Sinus Floor

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Each maxillary molar was classified into three types according to the vertical relationship between the root apex and the maxillary sinus floor (Figure 2). The distance from the root apex to the maxillary sinus floor was measured (Figure 2-a,b). If the root apex is located below the maxillary sinus floor, the distance value was made negative.

Type I The maxillary sinus floor is located above the root apex.

Type II The root apex and the maxillary sinus floor are in contact.

Type III From the buccal side, the maxillary sinus floor is lower than the mesiobuccal and distobuccal root apex. From the palatal side, the maxillary sinus floor is lower than the palatal root apex.

Statistical Analysis

Statistical analyses were performed using SPSS software (version 12.0, SPSS Inc, Chicago, IL, USA). Measurements of the alveolar bone thickness from the root to the alveolar bone surface and the distance from the root apex to the maxillary sinus floor between the maxillary first and second molar, male and female were evaluated using 2-sample t tests. Differences with a P value <.05 were considered statistically significant.

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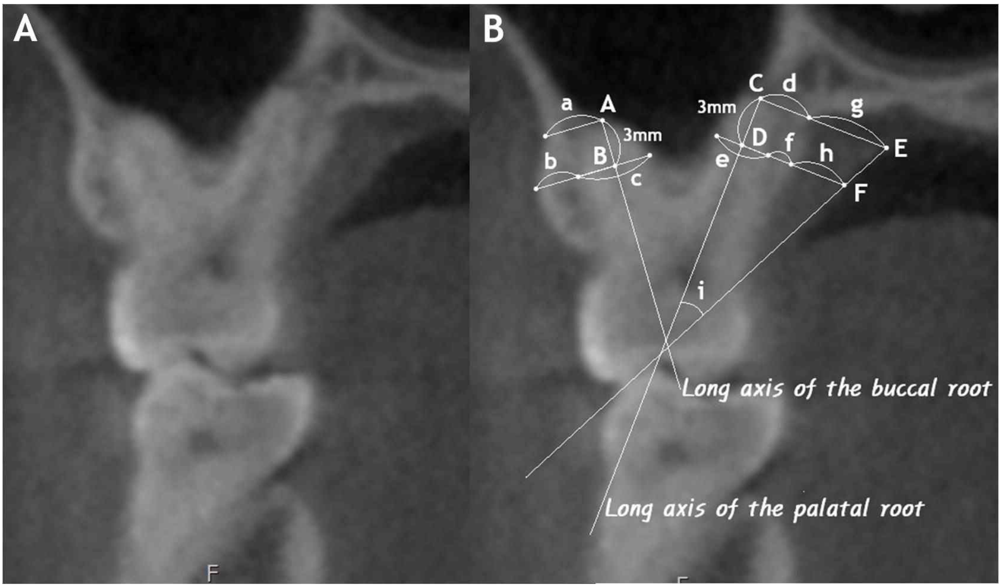

Figure 1. A) Coronal CBCT image selected for analysis. B) Measurements in the coronal CBCT image. A) Buccal root apex. B) 3mm below buccal root apex. C) Palatal root apex. D) 3mm below palatal root apex. E) Palatal soft tissue surface at the root apex level. F) Palatal soft tissue surface at the root-3mm level. a) Alveolar bone thickness from root apex to buccal bone surface. b) Alveolar bone thickness from resected root surface to buccal bone surface. c) Buccolingual width of resected buccal root section d) Alveolar bone thickness from root apex to palatal bone surface. e) Buccolingual width of resected palatal root section. f) Alveolar bone thickness from resected root surfaces to palatal bone surface. g) Palatal soft tissue thickness at the root apex level. h) Palatal soft tissue thickness at the root-3mm level. i) The angle between the straight line connecting E and F and the palatal root axis.

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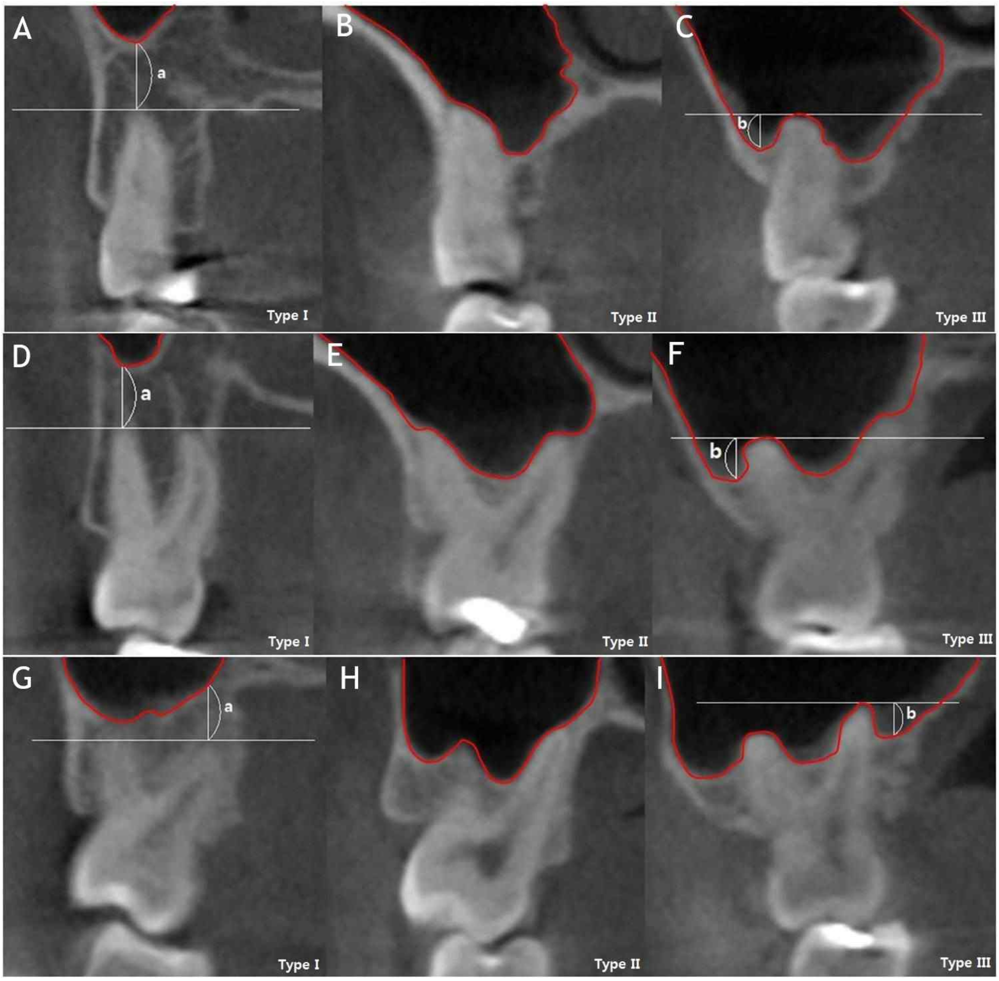

Figure 2. Classification of the vertical relationship between the root apex of the maxillary molar and the maxillary sinus floor. A) Type I mesiobuccal root. B) Type II mesiobuccal root. C) Type III mesiobuccal root. D) Type I distobuccal root. E) Type II distobuccal root. F) Type III distobuccal root. G) Type I palatal root. H) Type II palatal root. I) Type III palatal root; a) The distance from Type I root apex to the maxillary sinus floor (positive value). b) The distance from Type III root apex to the maxillary sinus floor (negative value).

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III. Results

Relationship Between Maxillary Molar Root and Alveolar Bone

Alveolar Bone Thickness

Alveolar bone thickness and buccolingual width of resected root section (mm± SD) in Figure 1 was summarized in Table I. Buccal bone from root apex was the thickest in the mesiobuccal root of the maxillary second molar (6.53mm) and thinnest in the distobuccal root of the maxillary first molar (4.55mm). Buccal bone from root-3mm was the thickest in the mesiobuccal root of the maxillary second molar (4.08mm) and thinnest in the mesiobuccal root of the maxillary first molar (2.43mm). Palatal bone from root apex was thicker in the maxillary first molar (4.01mm) than second molar (3.39mm). The thickness of the palatal alveolar bone from root-3mm of the maxillary first molar (2.08mm) and second molar (2.03mm) was similar.

Alveolar bone thickness and buccolingual width of resected root section of the maxillary first and second molar was shown in Table III. In case of buccal bone thickness from mesiobuccal root apex and root-3mm, there was significant difference between the maxillary first molar (4.61mm, 2.43mm) and second molar (6.53mm, 4.08mm) ($P<0.05$). In case of buccal bone thickness from distobuccal root apex and root-3mm, there was significant difference between maxillary first molar (4.55mm,3.16mm) and second molar (5.53mm, 3.72mm) ($P<0.05$). In case of palatal bone thickness from palatal root apex, there was significant difference between the maxillary first molar (4.01mm) and second molar (3.39mm) ($P<0.05$). In case of palatal bone thickness from palatal root-3mm, no significant difference was found between the maxillary first molar (2.08mm) and second molar (2.03mm).

Buccolingual Width of Resected Root Section

Buccolingual width of resected root section was the longest in the

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mesiobuccal root of the maxillary first molar (4.81mm) and shortest in the palatal root of the maxillary first molar (3.00mm).

There was no significant difference in the buccolingual width of resected mesiobuccal root section between the maxillary first molar (4.81mm) and second molar (4.74mm). In terms of buccolingual width of resected distobuccal root section, significant difference was found between the maxillary first molar (3.48mm) and second molar (3.35mm) ($P<0.05$). In case of buccolingual width of resected palatal root section, no significant difference was found between the maxillary first molar (3.00mm) and second molar (3.01mm).

The Distance from the Cortical Bone Surface to the End of the Resected Root during Endodontic Microsurgery

The length from the cortical bone surface to the end of the resected root during endodontic microsurgery was evaluated by the addition of the b and c, or e and f in Figure 1. The measured values were shown in Table IV. The distance was the longest in the mesiobuccal root of the maxillary second molar (8.82mm) and shortest in the palatal root of the maxillary second molar (5.04mm).

Comparison of Alveolar Bone Thickness and Buccolingual Width of Resected Root Section According to Sex

The statistical significance between male and female in the measured values was shown in Table V. When comparing the differences between male and female in mesiobuccal and distobuccal root of the maxillary first molar, male showed bigger values than female in terms of bone thickness from root apex and root-3mm and buccolingual width of resected root section ($P<0.05$). In case of palatal bone thickness from palatal root apex and root-3mm of the maxillary first molar, there were no significant

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differences between male and female ($P>0.05$). In terms of buccolingual width of resected root section of the maxillary first molar, male had bigger numbers than female ($P<0.05$).

Buccal bone thickness from root apex and root-3mm and buccolingual width of resected root section was greater in male than in female of mesiobuccal root of the maxillary second molar ($P<0.05$). Buccal bone thickness from distobuccal root apex of the maxillary second molar was bigger in male than in female, but there was no statistically significant difference ($P>0.05$). In case of buccal bone thickness at the distobuccal root-3mm level and buccolingual width of resected distobuccal root section of the maxillary second molar, male showed greater values than female ($P<0.05$). There was no significant difference in palatal bone thickness from palatal root apex and buccolingual width of resected palatal root section of the maxillary second molar between male and female ($P>0.05$). In case of palatal bone thickness from root-3mm of the maxillary second molar, male had bigger numbers than female ($P<0.05$).

Relationship Between Palatal Gingiva and Palatal Root

There was no significant difference in the angle between the straight line of the palatal gingival surface and the long axis of the root between the maxillary first molar (33.66°) and second molar (33.98°) (Table II). Palatal soft tissue was thicker at the maxillary second molar than the maxillary first molar ($P<0.05$).

Comparison of Relationship Between Palatal Gingiva and Palatal Root According to Sex

Figures for the relationship between the palatal gingiva and palatal root of male and female are given in Table VI. In case of soft tissue thickness at palatal root apex and root-3mm level of the maxillary first molar,

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there were no significant differences between male and female (P>0.05). The angle between the straight line of the palatal gingival surface and the long axis of the palatal root of the maxillary first molar was bigger in female than in male (P<0.05).

In case of soft tissue thickness at palatal root apex level of the maxillary second molar, there was no significant difference between male and female (P>0.05). The soft tissue thickness at palatal root-3mm level of the maxillary second molar was bigger in male than in female (P<0.05). The angle between the straight line of the palatal gingival surface and the long axis of the palatal root of the maxillary second molar was bigger in female than in male (P<0.05).

Vertical Relationship Between Maxillary Molar Root Apex and The Maxillary Sinus Floor

The measured values in Figure 2 were summarized in Table VII and VIII. In case of mesiobuccal and distobuccal root, the frequency in type III in the maxillary second molar (37%, 32.5%), in which a root apex protruded in the maxillary sinus floor, was higher than in the first molar (28%, 25.5%). In case of palatal root, the frequency in type III was higher in the maxillary first molar (20%) than in the second molar (6%).

Distance Between Root Apex and The Maxillary Sinus Floor

The mean distances from the mesiobuccal, distobuccal and palatal roots of the type I maxillary first molar to the maxillary sinus floor were 3.05mm (mesiobuccal), 2.86mm (distobuccal) and 3.06mm (palatal). The values for type I maxillary second molar were 2.73mm (mesiobuccal), 2.72mm (distobuccal) and 3.48mm (palatal). The mean distances from the mesiobuccal, distobuccal and palatal roots of the type III maxillary first molar to the maxillary sinus floor were -2.23mm (mesiobucccal), -2.88mm

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(distobuccal) and −1.47mm (palatal). The values from the mesiobuccal, distobuccal and palatal roots of type III maxillary second molar to the maxillary sinus floor were −2.63mm (mesiobuccal), −2.60mm (distobuccal) and −1.71mm (palatal).

There was no statistically significant difference in mean distance from root apex to the maxillary sinus floor between the maxillary first and second molar. In the palatal root of the type I maxillary second molar, the distance from the root apex to the maxillary sinus floor was longer in female than in male ($P<0.05$). In the mesiobuccal and distobuccal root of the type III maxillary first molar, the distance from the root apex to the maxillary sinus floor was longer in male than in female ($P<0.05$). The other roots did not show significant difference in mean distance from root apex to the maxillary sinus floor between male and female.

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Table I. Mean alveolar bone thickness between the bone surface and the maxillary molars roots and mean buccolingual width of resected root section (mm±SD).

Measurement	Maxillary 1st molar									Maxillary 2nd molar								
	MB			DB			P			MB			DB			P		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
Root apex-bone surface MB,DB : Fig.1-a P : Fig.1-d	4.91±2.19	4.29±1.58	4.61±1.93	4.85±1.85	4.24±1.38	4.55±1.66	3.92±1.28	4.11±1.50	4.01±1.39	6.79±1.87	6.26±1.78	6.53±1.84	5.66±1.79	5.40±1.96	5.53±1.87	3.32±1.59	3.47±1.58	3.39±1.58
root-3mm-bone surface MB,DB : Fig.1-b P : Fig.1-f	2.76±1.55	2.09±1.02	2.43±1.36	3.46±1.36	2.86±0.99	3.16±1.23	2.09±0.85	2.07±0.97	2.08±0.91	4.38±1.33	3.77±1.26	4.08±1.33	3.93±1.48	3.49±1.46	3.72±1.48	2.22±1.31	1.83±1.07	2.03±1.21
Buccolingual width of resected root section MB,DB : Fig.1-c P : Fig.1-e	4.97±1.14	4.64±0.94	4.81±1.05	3.56±0.57	3.39±0.62	3.48±0.60	3.07±0.52	2.93±0.43	3.00±0.48	5.08±1.02	4.39±0.85	4.74±1.00	3.48±0.60	3.22±0.55	3.35±0.59	3.12±1.22	2.90±0.47	3.01±0.94

MB, mesiobuccal; DB, distobuccal; P, palatal.

Table II. Mean soft tissue thickness (mm±SD) at the palatal root apex level and root-3mm level and mean angle(° ±SD) between the straight line of the palatal gingival surface and the long axis of the palatal root.

Measurement	Maxillary 1st molar P			Maxillary 2nd molar P		
	Male	Female	Total	Male	Female	Total
Soft tissue thickness at root apex level (Fig.1-g)	5.15±1.88	5.41±1.82	5.28±1.85	6.50±2.93	6.97±2.49	6.73±2.72
Soft tissue thickness at root-3mm level (Fig.1-h)	3.19±1.52	3.36±1.67	3.27±1.60	3.75±2.02	4.34±1.94	4.04±2.00
Angle (Fig.1-i)	31.71±12.87	35.69±12.57	33.66±12.85	30.94±13.54	37.16±12.71	33.98±13.47

P, palatal.

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Table III. Mean alveolar bone thickness and mean buccolingual width of resected root section (mm±SD) of the maxillary first and second molar.

Measurement	MB		DB		P	
	1st Molar	2nd Molar	1st Molar	2nd Molar	1st Molar	2nd Molar
Root apex-bone surface	4.61*	6.53*	4.55*	5.53*	4.01*	3.39*
root-3mm-bone surface	2.43*	4.08*	3.16*	3.72*	2.08	2.03
Buccolingual width of resected root section	4.81	4.74	3.48*	3.35*	3.00	3.01

MB, mesiobuccal; DB, distobuccal; P, palatal.
*Indicate statistically significant difference between groups (P<0.05).

Table IV. Mean distance from the cortical bone surface to the end of the resected root during endodontic microsurgery (mm).

Maxilla		Distance Fig 1.- b+c (Buccal bone), e+f (Palatal bone)		
		Male	Female	Total
1st molar	MB (Buccal bone)	7.73	6.73	7.24
	DB (Buccal bone)	7.02	6.25	6.64
	P (Palatal bone)	5.16	5.00	5.08
2nd molar	MB (Buccal bone)	9.45	8.15	8.82
	DB (Buccal bone)	7.41	6.71	7.07
	P (Palatal bone)	5.34	4.73	5.04

MB, mesiobuccal; DB, distobuccal; P, palatal.

Table V. Mean alveolar bone thickness and mean buccolingual width of resected root section (mm) of male and female.

Maxilla	1st Molar MB		1st Molar DB		1st Molar P		2nd Molar MB		2nd Molar DB		2nd Molar P	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Root apex-bone surface	4.91*	4.29*	4.85*	4.24*	3.92	4.11	6.79*	6.26*	5.66	5.40	3.32	3.47
root-3mm-bone surface	2.76*	2.09*	3.46*	2.86*	2.09	2.07	4.38*	3.77*	3.93*	3.49*	2.22*	1.83*
Buccolingual width of resected root section	4.97*	4.64*	3.56*	3.39*	3.07*	2.93*	5.08*	4.39*	3.48*	3.22*	3.12	2.90

MB, mesiobuccal; DB, distobuccal; P, palatal.
*Indicate statistically significant difference between groups (P<0.05).

Table VI. Mean soft tissue thickness (mm) and mean angle (°) between the straight line and the palatal root axis of the maxillary first and second molar, male and female.

Maxilla	1st Molar P		2nd Molar P		1st Molar P	2nd Molar P
	Male	Female	Male	Female	Total	Total
Soft tissue thickness at the root apex level	5.15	5.41	6.50	6.97	5.28*	6.73*
Soft tissue thickness at the root-3mm level	3.19	3.36	3.75*	4.34*	3.27*	4.04*
Angle	31.71*	35.69*	30.94*	37.16*	33.66	33.98

P, palatal.
*Indicate statistically significant difference between groups (P<0.05).

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Table VII. Vertical relationship between root apex of the maxillary molar and the maxillary sinus floor.

	Maxillary 1st molar									Maxillary 2nd molar								
	MB,n(%)			DB,n(%)			P,n(%)			MB,n(%)			DB,n(%)			P,n(%)		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
Type I	24(23.53)	51(52.04)	75(37.5)	21(20.59)	46(46.94)	67(33.5)	21(20.59)	42(42.86)	63(31.5)	14(13.73)	26(26.53)	40(20)	20(19.61)	42(42.86)	62(31)	50(49.02)	72(73.47)	122(61)
Type II	42(41.18)	27(27.55)	69(34.5)	49(48.04)	33(33.67)	82(41)	56(54.90)	41(41.84)	97(48.5)	38(37.25)	48(48.98)	86(43)	34(33.33)	39(39.80)	73(36.5)	45(44.12)	21(21.43)	66(33)
Type III	36(35.29)	20(20.41)	56(28)	32(31.37)	19(19.39)	51(25.5)	25(24.51)	15(15.31)	40(20)	50(49.02)	24(24.49)	74(37)	48(47.06)	17(17.35)	65(32.5)	7(6.86)	5(5.10)	12(6)

MB, mesiobuccal; DB, distobuccal; P, palatal.

Table VIII. Mean distance (mm±SD) from the maxillary sinus floor to root apex.

	Maxillary 1st molar									Maxillary 2nd molar								
	MB			DB			P			MB			DB			P		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
Type I distance (Fig.2-a)	3.96±4.05	2.62±2.45	3.05±3.09	3.77±4.30	2.45±2.55	2.86±3.23	2.74±2.68	3.22±2.87	3.06±2.80	3.54±4.31	2.29±1.59	2.73±2.86	3.21±4.01	2.48±1.80	2.72±2.70	2.48±1.96	4.17±2.83	3.48±2.63
Type II distance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Type III distance (Fig.2-b)	-2.60±1.96	-1.57±0.81	-2.23±1.71	-3.32±2.40	-2.15±1.09	-2.88±2.08	-1.47±0.69	-1.47±0.83	-1.47±0.74	-2.68±2.00	-2.52±2.50	-2.63±2.16	-2.34±1.89	-3.32±2.96	-2.60±2.24	-1.37±0.59	-2.19±1.10	-1.71±0.90

MB, mesiobuccal; DB, distobuccal; P, palatal.

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Ⅳ. Discussion

The purpose of this study is the analysis of anatomic structure of maxillary molar using CBCT. The most common causes of endodontic failure were leaky canal and missing canal and some parts of the causes caused by the porous tubular structure of dentin and canal irregularities or a limitation of materials might be difficult to resolve[17]. Successful endodontic microsurgery can be performed when the position of root apex in the alveolar bone, the distance from alveolar bone surface to root apex, the root thickness and the relationship between maxillary sinus floor and root apex are accurately understood by analysing CBCT images.

Selection of Cross-sectional Plane in CBCT images

In the study of Lavasani et al[11] and SH Kang et al[19], the analysis was performed using CBCT axial view. On the other hand, JK Jang et al[20] used CBCT coronal view. However analysis of all planes of CBCT images before endodontic microsurgery is important. Especially, in the case of endodontic microsurgery of maxillary molars, the coronal image can be used to determine the instrument approach angle to the root apex and alveolar bone removal thickness required until reaching the root apex. Axial view evaluation has limitations in measuring the actual instrument approach angle and alveolar bone thickness. C.M. Giacomino et al[21] introduced targeted endodontic microsurgery (EMS), which uses 3-dimensional-printed surgical guides (3DSGs) and trephine burs to achieve single-step osteotomy and root-end resection. They used the coronal plane of CBCT images to evaluate the path of trephine bur. Assuming real endodontic microsurgery in order to more accurately determine the root apex position and root-3mm resection locations and analysis alveolar bone thickness required and instrument operation angle, our study was performed using coronal CBCT

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images.

Relationship Between Maxillary Molar Root and Alveolar Bone

Alveolar Bone Thickness

From a biological point of view, the most appropriate apical resection angle is perpendicular to the long axis of the root.[22] The theoretical basis of vertical root resection is as follows. First, a vertical resection at approximately 3mm of the anatomical root apex is likely to include most of the branches present in the root end.[23] Secondly, as the resection angle increases, the number of dentinal tubules communicating with the root system around the root end increases. This greatly increases the likelihood that the irritating agent in the root canal system enters the healing tissue.[24,25] Third, vertical root resection provides a good healing environment and prevents root fractures by uniformly distributing the pressure applied to the root during biting.[26] Based on these reasons, alveolar bone thickness was measured by drawing a vertical line from the long axis of the root to the surface of the alveolar bone in this study.

Table IX compared our study with other studies. When the relationship between alveolar bone surface and root apex was evaluated in the maxillary molars, SH Kang et al[19], JK Jang et al[20] and Eberhardt et al[29] found buccal bone thickness was the thickest in the mesiobuccal root apex of the maxillary second molar (4.25mm, 4.99mm, 3.47mm). Similarly, our study demonstrated that buccal bone from root apex was the thickest in the mesiobuccal root of the maxillary second molar (6.53mm). The palatal bone thickness from the root apex of the maxillary first and second molar were 3.22mm (maxillary first molar) 3.27mm (maxillary second molar) in GC Jin's study[17] and 3.15mm (maxillary first molar) 3.08mm (maxillary second molar) in JK Jang's study[20] and 3.01mm (maxillary first molar) 2.76mm (maxillary

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second molar) in Eberhardt's study.[29] In our study, the palatal bone thickness at root apex was 4.01mm for the maxillary first molar and 3.39mm for the maxillary second molar.

Table IX. Comparison of alveolar bone thickness and buccolingual width of resected root section between studies (mm).

Measurement		Maxillary 1st molar			Maxillary 2nd molar		
		MB (Buccal bone)	DB (Buccal bone)	P (Palatal bone)	MB (Buccal bone)	DB (Buccal bone)	P (Palatal bone)
Root apex-bone surface	Our study	4.61	4.55	4.01	6.53	5.53	3.39
	Eberhardt et al	2.22	1.72	3.01	4.25	3.19	2.76
	GC Jin et al	2.97	2.73	3.15	4.63	3.61	3.08
	SH Kang et al	3	3.13		4.99	3.99	
	JK Jang et al	2.33	2.31	3.22	5.13	3.47	3.27
root-3mm-bone surface	Our study	2.43	3.16	2.08	4.08	3.72	2.03
	Lavasani et al	0.84	1.19	1.24	1.91	1.52	1.31
Buccolingual width of resected root section	Our study	4.81	3.48	3	4.74	3.35	3.01
	Lavasani et al	5.49	4.24	4.04	5.22	4.02	3.81

MB, mesiobuccal; DB, distobuccal; P, palatal.

Kim et al[27] found that for most roots, a 3.0mm resection eliminates 98% of apical ramifications and 93% of the lateral canals. In case of buccal bone thickness from root-3mm, the thickest bone was found over the mesiobuccal root of the second molar (1.91mm) in the Lavasani's study.[11] Our study also showed the thickest buccal bone thickness (4.08mm) at the mesiobuccal root-3mm resection level in the maxillary second molar. Lavasani et al[11] demonstrated that palatal bone thickness from root-3mm were 1.24mm, 1.31mm in the palatal root of the maxillary first and second molar, respectively. In our study, there was no significant difference in the palatal bone thickness from palatal root-3mm between maxillary first molar (2.08mm) and second molar (2.03mm).

In other studies, they measured the horizontal distance from the root

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apex to the alveolar bone in the axial CBCT view.[11,17,19] In our study, assuming the endodontic microsurgery, we measured the distance from the root apex to the buccal and palatal bone perpendicular to the root axis in the coronal CBCT view. For this reason, buccal and palatal bone thickness was measured larger in our study than other studies.

Buccolingual width of resected root surface

Lavasani et al[11] found that the thickest buccolingual width belonged to mesiobuccal root of the maxillary first molar at 5.49mm and the palatal root of the maxillary second molar had the smallest thickness at 3.81mm. In our study, the longest buccolingual width of resected root section was the mesiobuccal root of the maxillary first molar at 4.81mm and the shortest buccolingual width of resected root section was the palatal root of the maxillary first molar at 3.00mm. In both studies, the root with the longest resection length was the mesiobuccal root of the maxillary first molar, but the overall resection length was longer in Lavasani's study.[11] The reason for the numerical difference between the two studies is thought to be racial differences.

The Distance from the Cortical Bone Surface to the End of the Resected Root during Endodontic Microsurgery

Lavasani et al[11] found that the longest resection distance was for the mesiobuccal root of the second molar (7.40mm). Similarly, in our study, the root that needed the deepest access from the alveolar bone surface to the end of the root apex was the mesiobuccal root of the maxillary second molar (8.82mm). In the buccal root, the maxillary second molar required a deeper approach length than the maxillary first molar ($P<0.05$). For palatal root, there was no significant difference in the approach distance between the maxillary first and second molar ($P>0.05$). Men needed a longer

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approach length than women and there were significant differences except for the palatal root of the maxillary first molar.

Relationship Between Palatal Gingiva and Palatal Root

Palatal Approach for Endodontic Microsurgery of Palatal Root

If resection of the palatal root of the maxillary molar is necessary, the clinician must decide whether to take a buccal or palatal approach. Jin et al[17] found the thicknesses from the palatal root apex to the buccal bone surface in the maxillary first and second molars were 10.69mm and 10.17mm, respectively. In the Rigolone's study[30], mean buccal bone thickness from root apex to the buccal cortex was found to be 9.73mm in the maxillary first molar. Jin et al[17] suggested that the palatal approach may be a feasible option because the buccal surgical approach of the maxillary molar palatal root requires a large amount of bone removal.

The angle measured as i in Figure 1 was 33.66° and 33.98° degrees in the maxillary first and second molars. The bigger this angle, the lower the palatal position and the more difficult the instrument will be to access during endodontic microsurgery. Knowing this angle in advance of the palatal approach endodontic microsurgery can determine the difficulty of the operation. For women, this angle was larger than for men, and it can be expected that access to the instrument will be more difficult during endodontic microsurgery.

C.M. Giacomino et al[21] introduced targeted endodontic microsurgery (EMS), which used 3-dimensional-printed surgical guides (3DSGs) and trephine burs to achieve single-step osteotomy, root-end resection, and biopsy in complex cases. When performing an palatal approach of the endodontic microsurgery for palatal root of the maxillary molar, evaluation of soft tissue thickness and root axis angle in the coronal CBCT image may help in the manufacture of surgical guides. Knowing the soft tissue thicknesses in

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advance through CBCT analysis may be helpful when removing soft tissue using trephine bur.

Vertical Relationship Between Root Apex and The Maxillary Sinus Floor

In SH Kang's study[19], the vertical relationships between the maxillary sinus floor and the root apices for maxillary molars were classified as follows: group 1, the root apex was protruding into the sinus cavity; group 2, the root apex was in contact with the maxillary sinus floor; and group 3, the root apex was below the maxillary sinus floor. Compared to our study, Type I and Group 3, Type II and Group 2, Type III and Group 1 were similar. Table X summarized the results of both studies. In both studies, Type III was more frequent in the maxillary second molar than the first molar except for the palatal root of the maxillary second molar. In addition, the buccal root had a higher frequency of type III than the palatal root. In particular, the palatal root of the maxillary second molar had low type III frequency.

Depending on the location of the maxillary sinus floor, the difficulty of endodontic microsurgery is determined. If the maxillary sinus floor is placed below the root apex, endodontic microsurgery may be impossible or an additional procedure such as maxillary sinus elevation may be required. In all assessed roots, male had a higher Type III frequency than female.

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Table X. Comparison of the vertical relationship between root apex of maxillary molar teeth and maxillary sinus floor between studies.

Measurement		Maxillary 1st molar			Maxillary 2nd molar		
		MB,n(%)	DB,n(%)	P,n(%)	MB,n(%)	DB,n(%)	P,n(%)
The MSF is located above root apex	Type I in our study	75(37.5)	67(33.5)	63(31.5)	40(20)	62(31)	122(61)
	Group 3 in SH Kang et al	109(41.3)	113(42.8)	106(40.2)	65(30.7)	77(36.3)	111(52.4)
The MSF and root apex are in contact	Type II in our study	69(34.5)	82(41)	97(48.5)	86(43)	73(36.5)	66(33)
	Group 2 in SH Kang et al	90(34.1)	101(38.3)	80(30.3)	71(33.5)	80(37.7)	74(34.9)
The MSF is lower than the root apex	Type III in our study	56(28)	51(25.5)	40(20)	74(37)	65(32.5)	12(6)
	Group 1 in SH Kang et al	65(24.6)	50(18.9)	78(29.5)	76(35.8)	55(25.9)	27(12.7)

MSF, Maxillary sinus floor; MB, mesiobuccal; DB, distobuccal; P, palatal.

Our research has several limitations. First, the CBCT images used in the analysis were mostly from young Korean patients. Most patients visited for wisdom tooth extraction and mean age was 25.91 years old. In particular, the percentage of patients in their 40s and 50s was very small. In real clinical, patients in need of surgical root canal treatment will be in 40s and 50s. To complement the limitation of our research, analysis of CBCT images of different ages will be required. Especially, the CBCT image analysis of older patients over 40 years of age will be required. Also, since the subject studied was a healthy tooth, further anatomical evaluation of the affected tooth would be needed. Second, due to the resolution limitations of CBCT images, the analyst's subjectivity was involved. To improve these limitations, we need the CBCT image with better resolution. Third, in this study, only teeth with 3 separated roots were analyzed. The fused root is very difficult for endodontic microsurgery. So, intentional replantation is the primary treatment option for the case of a fused root. Adding these type of root may result in a higher frequency of teeth that are difficult to access to the buccal or palatal root.

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V. Conclusion

Alveolar bone thickness from maxillary molar root to cortical bone surface, buccolingual width of resected root section and vertical relationship between root apex of maxillary molar and maxillary sinus floor differed according to root type and sex. This study was the first evaluate the angle between the straight line of the palatal gingival surface and the long axis of the root and soft tissue thickness at the palatal root apex and 3mm resected root level. When attempting palatal approach for endodontic microsurgery of maxillary molar palatal root, evaluation between the palatal root and the surrounding anatomical structures should be used to identify appropriate indications using CBCT analysis. But the palatal approach is a very difficult treatment. So prior non-surgical root canal treatment of the palatal root should be performed with great care.

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CHOSUN UNIVERSITY

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