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Classification of the root canal of the Korean maxillary first molar using microcomputed tomography

Jong-Wook Park, Ki-Suk Paik, Mi-Sook Chang, Seung-Pyo Lee*

Department of Oral Anatomy, Dental Research Institute and School of Dentistry, Seoul National University

I. Introduction

A detailed understanding of the complex root canal system is essential for the successful endodontic treatment. Three dimensional knowledge of the morphology of the root canal aids the clinician in successful cleaning, shaping, and obturation of the root canal system. Information on the overall root canal structure such as the number of root, the configuration of the canal system and the incidence of the accessory canal are believed to the basics for the endodontic practitioners[1,2]. Ambiguous knowledge of the root canal system may lead to a false diagnosis, improper cleaning of the debridement, breaking instruments and other severe problems in a root canal treatment. Quantitative knowledge of the precise location of the accessory canals, the root canal curvature pattern, and the taper of the root canal might enhance the quality of the endodontic treatment and provide basic research materials for the development of clinical techniques and devices. Such clinical importance has led to many studies particularly on molars, which have a relatively higher structural complexity than the incisors and canines.

The maxillary first molar is a major research target owing to its clinical significance and complex root canal system. The majority of the maxillary first molar have a high probability of the secondary mesiobuccal root canal (MB2 canal). Therefore, the routine radiograph normally obtained should be supplemented by a view from distal, taken at a different horizontal angle in endodontic treatment. The mesiobuccal root of the maxillary first molar shows a high incidence of the isthmus, which is a narrow, ribbon-shaped communication between two root canals[3]. The connection of the isthmus can be observed between any two root canal systems that occur within one root. A isthmus of the canal can function as a bacterial reservoir, an obstacle to the cleaning canal debris, and result in post-endodontic treatment pain. Many studies have shown various results in anatomy of the maxillary

* 교신저자
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first molar according to the research design or experiment methods. For example, the study on the incidence of the MB2 canal of the maxillary first molar has been reported to range from 30% to more than 90%[4]. The palatal root and disto-buccal root of maxillary first molar possessed high incidence of a simple canal configuration in many previous studies[5,6]. The result of this study is also influenced by racial differences. However, there is little information on the canal anatomy of Asian maxillary first molar, and there are few results obtained from microcomputed tomography (MCT).

During the last few decades, a number of methodologies have been described to study canal morphology. One of the latest innovations in the industrial and medical field is the use of MCT for the purpose of the study. Any conventional optical or electron microscope allows visualizing only two dimensional images of a specimen surface or thin slices. However, in most cases, a final conclusion about original three dimensional object structures cannot be made on the base of two dimensional information. One can obtain the three dimensional information of object structures by cutting them into very thin slices, which can then be visualized in the light microscope and interpolate the two dimensional information into a three dimensional structure model. However, this method is not only very cumbersome but also not very reliable since the object structure itself can be altered by the preparation technique and the distance between the slices is usually too coarse to avoid loss of three dimensional information. An x-ray radiography system produces two dimensional shadow images of complete internal three dimensional structures, but in a single two dimensional shadow projection the depth information is completely mixed. Only an x-ray tomography system allows us to visualize and measure complete three dimensional object structures without sample preparation or chemical fixations. This scientific tool could develope a potential in research of pulp anatomy as well. There was study carried out observation of the teeth in computerized tomographic (CT) scans. With using CT images, a three dimensional (3D) analysis was conducted for further visualization[7]. However, they concluded that detailed observations could not be made with this technique. Typically the spatial resolution of conventional medical CT-scanners is in the range of 1 - 2.5 mm, which corresponds to 1 - 10 cubic mm voxel (volume element) size. Nowadays improvements in technology have led to a miniaturized form, called microcomputed tomography, with the advances in imaging software. As a result, microcomputed tomography gives possibilities to improve the spatial resolution by seven to eight orders in the volume terms. Microcomputed tomography allows to reach a spatial resolution of 5 μm corresponding to near 1×10^{-7} cubic mm voxel size. It has been reported that MCT is a noninvasive technique that possesses the ability to visualize morphological characteristics in detailed and accurate data without destruction of the tooth[8]. MCT offers reproducible data in all three dimensional planes and qualitative, quantitative results[9].

The aim of this study was to classify the root canal of the maxillary first molar in a Korean population using MCT with developed image software.

Materials and Methods

The overall methodology of this study includes preprocessing of the collected teeth, slice image acquisition using MCT, processing of the acquired images for remodeling, three dimensional remodeling of the root canal system with the 3D image processing software and inspection of the root canal system (Fig. 1).

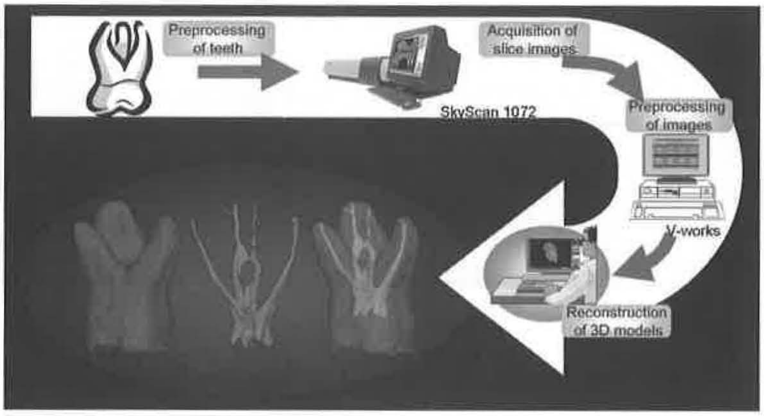

Fig. 1. Overall process of constructing the 3D model of the root canal (acquire two dimensional images, image restoration, image enhancement, image segmentation, three dimensional reconstruction and visualization).

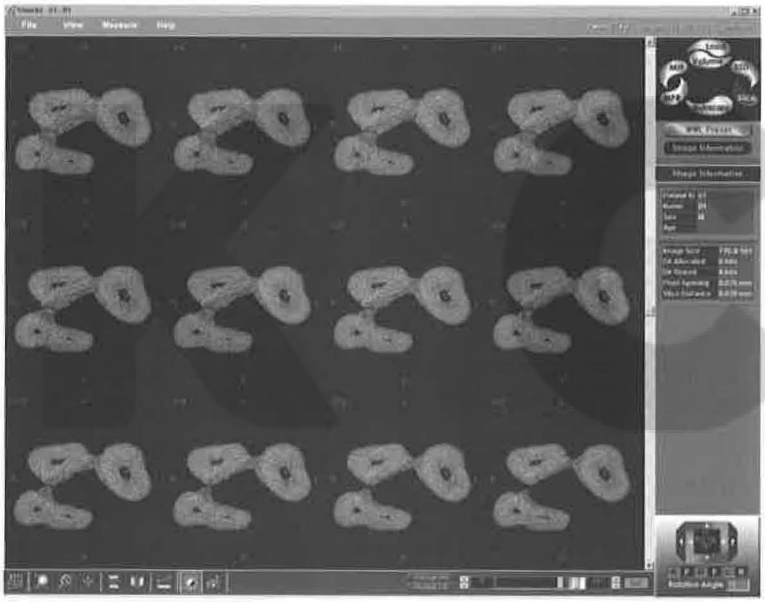

Fig. 2. Slice images of the maxillary first molar acquired with MCT displayed in V-works 3D remodeling software (number 232-243 slice images of 502 images of the maxillary first molar).

Fifty-three maxillary first molars from Korean adults were collected from dentists in local dental clinics. The teeth were obtained from those patients who had sound extracted teeth due to periodontal problems. All the patients provided informed consent to the extracted teeth being used in this study. All the attached calculus and soft tissue were removed using an ultrasonic scaler and 4% sodium hypochlorite. The teeth were scanned using a desktop x-ray MCT scanner (Skyscan 1072-80 kV, Skyscan b.v.b.a., Aartselaar, Belgium) with x-ray spot size < 8 μm@ 8W, 20-80 kV, 1-100 μA and 1024 X 1024 12 bit digital CCD x-ray detector. Detail detectability is 3 μm and low contrast resolution is 8 μm. Pixel size is < 20 μm and cross sectional distance is < 40 μm. Five hundred and two slice images per tooth were acquired using MCT. The slice thickness was 39.0 μm and each image has 1024 X 1024 pixels with a 19.5 μm spatial resolution (Fig. 2). A three dimensional model of the root canal (Fig. 3) was reconstructed with a 3D

Fig. 3. Constructed 3D model of the external surface of the maxillary first molar (left), the root canal of the maxillary first molar (middle), and an overlapped image of the external surface and root canal (right).

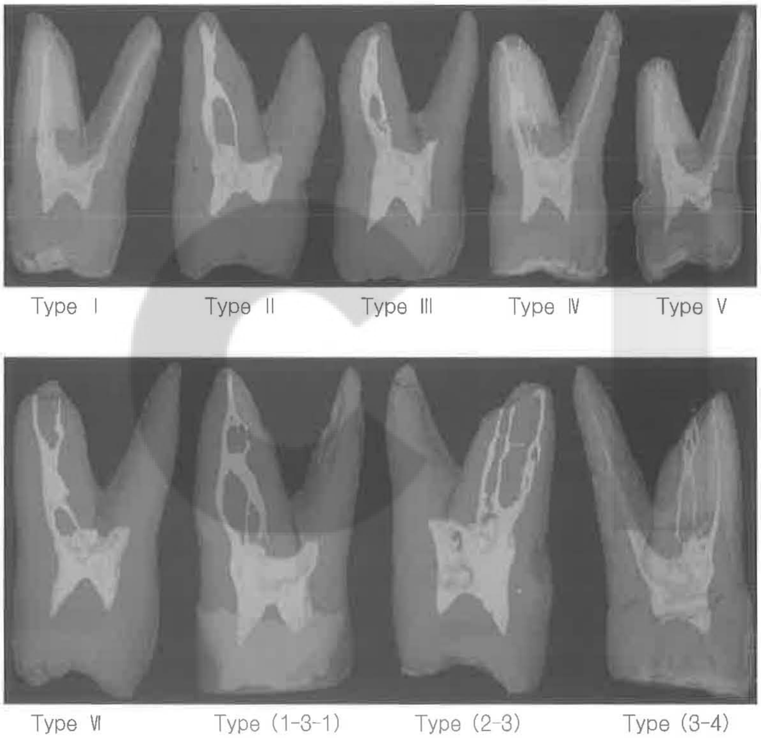

Fig. 4. Classification of the root canal configurations present within the mesiobuccal root of the maxillary first molar. Type Ⅰ: A single canal extends from the pulp chamber to the apex. Type Ⅱ: Two separate canals leave the pulp chamber and join short of the apex to form one canal. Type Ⅲ: One canal leaves the pulp chamber, divides into two within the root, and then merges to exit as one canal. Type Ⅳ: Two separate and distinct canals extend from the pulp chamber to the apex. Type Ⅴ: One canal leaves the pulp chamber and divides short of the apex into two separate and distinct canals with separate apical foramina. Type Ⅵ: Two separate canals leave the pulp chamber, merge in the separate canals leave the pulp chamber, merge in the body of the root, and redivide short of the apex to exit as two distinct canals. Type (1-3-1): One canal leaves the pulp chamber, divides into three within the root, and then merges to exit as one canal. Type (2-3): Two separate canals leave the pulp chamber, exit as three distinct canals. Type (3-4): Three separate canals leave the pulp chamber, exit as four distinct canals.

remodeling software (V-works 4.0, Cybermed Inc., Seoul, Korea) on a personal computer (CPU: Pentium 4, 2.4 GHz, RAM: 2G byte, OS: Windows 2000).

Using the reconstructed model, the root canal system was classified according to Vertucci's classification (Fig. 4). The location of the accessory canal was also investigated (Fig. 5).

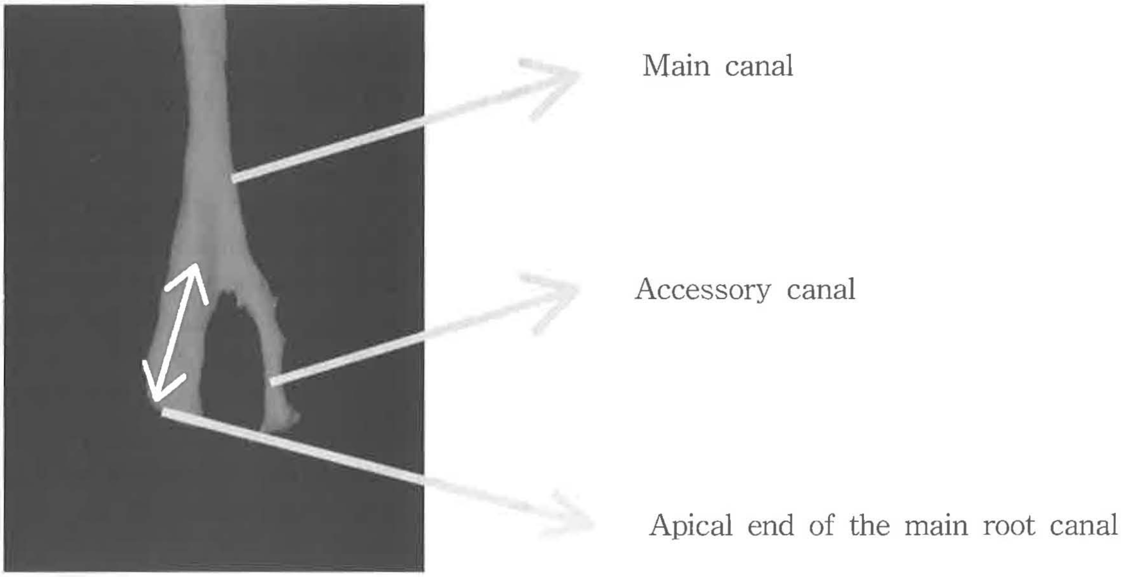

Fig. 5. Diverging location of the accessory canal from the main canal.

Ⅲ. Results

The mesiobuccal canal showed various types (Type Ⅰ : 15.1%, Type Ⅱ : 7.5%, Type Ⅲ : 7.5%, Type Ⅳ : 20.8%, Type Ⅴ : 7.5%, Type Ⅵ : 26.4%, Type 1-3-1 : 3.8%, Type 2-3 : 9.4%, Type 3-4 : 1.9%), whereas the distobuccal and palatal canal showed the simpler types. The frequency of one, two and three canals in the mesiobuccal root corresponded to 22.6% (Type Ⅰ + Type Ⅴ), 62.3% (Type Ⅱ + Type Ⅲ + Type Ⅳ + Type Ⅵ) and 15.1% (Type 1-3-1 + Type 2-3 + Type 3-4) respectively. More than 77% (two canal root + three canal root) of the mesiobuccal canal had a secondary mesiobuccal canal. 96.2% of the distobuccal canal and 100% of the palatal canal showed the Type Ⅰ configuration (Table 1).

Table 1. Classification of the root canal system in the maxillary first molar (N(%))

	N	Type Ⅰ	Type Ⅱ	Type Ⅲ	Type Ⅳ	Type Ⅴ	Type Ⅵ	Type 1-2-1-2	Type 1-3-1	Type 2-3	Type 3-4
MB canal	53	8(15.1)	4(7.5)	4(7.5)	11(20.8)	4(7.5)	14(26.4)		2(3.8)	5(9.4)	1(1.9)
DB canal	53	51(96.2)	-	-	1(1.9)	-	-	1(1.9)			
P canal	53	53(100)	-	-	-	-	-	-			

MB: mesiobuccal, DB: distobuccal, P: palatal N: Total number
one canal root : Type Ⅰ, Type Ⅴ (Type Ⅴ can be regarded as one canal root clinically)
two canal root : Type Ⅱ, Type Ⅲ, Type Ⅳ, Type Ⅵ
three canal root : Type 1-3-1, Type 2-3, Type 3-4

The distance between the apex of main canal and the accessory canal was 1.36 mm, 0.98 mm and 1.51 mm in the mesiobuccal, distobuccal and palatal canal, respectively (Table 2).

Table 2. Location of the accessory canal (Distance between the apex of the main canal and accessory canal (mm))

	M ± SD
MB canal	1.36 ± 0.87
DB canal	0.98 ± 0.42
P canal	1.51 ± 0.71

MB: mesiobuccal, DB: distobuccal, P: palatal M: Mean, SD: Standard deviation

Ⅳ. Discussion

Applying MCT and 3D remodeling software to the examination of the root canal morphology provide several advantages over traditional methodologies such as a radiographic inspection, a cross sectional inspection and a clearing technique. One of the benefits of MCT and 3D remodeling software is the precise reproduction of the internal structure of the root canal system. The actual spatial resolution of Skyscan is 20 μm as a result of the noise level due to the scanning conditions, although the theoretical scanning spatial resolution of Skyscan 1072 is 5 μm. This scanning resolution can provide a sufficiently detailed model for this study. Table 1 shows that the mesiobuccal root of the maxillary first molar exhibited a wide variation in the root canal configurations. These results are different from other previous researches, which could be the result of various factors such as racial differences, specimen source, detectability of the obstructed accessory canals due to formation of the secondary dentin with age, treatment method of the pulpal tissue, and resolution power of the MCT. The fine resolution of the SkyScan 1072 in this experiment might explain the different result of the canal type classification with the other research shown in Table 3.

Compared to studies using the clearing technique, this study showed a lower incidence of the simpler canal type I, II, and a higher incidence of the more complex canal type VI and the additional type. One of the contributing factors might be the detectability of the constricted or discontinued canals, which results from calcification, in microcomputed tomography.

The mesiobuccal canal shown in Fig. 3 shows the type VI configuration. However, it might be mistaken for the type II because it is possible to miss the rest of the ① area in the clearing technique due to the decalcification end point, incomplete or uneven decalcification, incomplete dehydration, and the ink penetration ability[13].

The incidence of the accessory canal showed different results compared with previous reports.

Table 3. Comparison of the result of mesiobuccal root canal system type with other studies (%)

	Type I	Type II	Type III	Type IV	Type V	Type VI	Additional Types
This study (2004)	15.1	7.5	7.5	20.8	7.5	26.4	15.1
Wasti *et al.* (2001)[10]	33.3	23.3	-	23.3	13.3	6.8	-
Ng *et al.* (2001)[11]	30.0	25.6	1.1	33.3	6.7	-	3.3
Alavi *et al.* (2002)[12]	32.7	17.3	1.9	44.2	1.9	-	1.9

Fig. 6. The mesiobuccal canal with the Type VI and accessory canal (left) could be mistaken for the type II with no accessory canal (right) in clearing technique because of the discontinued, calcification area of in ① and ②. MB : mesiobuccal canal, MB2 : secondary mesiobuccal canal, DC : distobuccal canal, PC : palatal canal

This study showed a 47.2%, 24.5%, and 18.9% incidence of the accessory canal in the mesiobuccal, distobuccal and palatal canals, respectively, which is much higher than that reported by Ng *et al.*[11] and Alavi *et al.*[12] who reported an 8.1% and 7.1% incidence of an accessory canal, respectively. These differences may be due to the fact that the calcified or constricted region of accessory canal of the ② area in Fig. 6 was not detected in clearing technique. In this study, the calcified or constricted region of accessory canal can be detected more precisely by slight altering threshold value of scanning condition.

In dental practice, the prevalence and location of the MB2 canal is very important in a root canal treatment of the maxillary first molar. This canal usually originates from the lingual and is slightly distal to the main mesiobuccal canal. Although the location of the canal orifice was confirmed, it is very difficult to clean and enlarge a full canal length mechanically. Therefore, remnants of the pulp tissue could be a source of an infection, and there might be some chance of endodontic treatment failure. Therefore, dentists need to know the root canal morphology of the complex mesiobuccal root canal and have skills to locate, clean and shape the complex root canal system for successful endodontic treatment.

In clinical endodontic treatments, the incidence of the accessory canal is also an important consideration factor in the removal of inflamed pulp tissue or necrotic debris within the root canal systems. In clinical practice, untreated accessory canals might be contributing factors to endodontic failure. Clinicians need to identify these accessory canals location and frequency when the root resection therapy is needed. Table 2 shows that the apical third of the roots of the maxillary first molar had a high prevalence of accessory canals, which explain the high frequency of root resection treatments for the maxillary first molar. Clinicians need to resect the minimum 3 mm of the apical foramen in order to eliminate the infected accessory canals, as showed in the location of the accessory canals shown in Table 2.

The MCT methodology has several advantages. The main advantage is that all the data collected from the intact teeth is available for a further evaluation and analysis of different planes. In addition, MCT data acquisition and evaluation can be performed in a matter of a few days[14,15]. Therefore, the non-destructive and rapid data acquisition are great advantages compared with the conventional histology and various other methods.

V. Conclusion

Quantitative measurements of the three dimensional tooth model are great advantage in study of pulp antomy. Microcomputed tomography is a reproducible and reliable technique for the three dimensional analysis of the root canal systems and can be applied quantitatively as well as qualitatively. This study classified root canal type of the maxillary first molar and demonstrated the average location of the accessory canal, which might be used as basic materials for the development of clinical techniques such as the dissection location in the apicoectomy. In conclusion, knowledge of these datas may help clinicians in performing endodontic therapy of Korean maxillary first molar.

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- 국문초록 -

미세전산화 단층촬영술을 이용한 한국인 상악제일대구치의 치근관 분류

박종욱, 백기석, 장미숙, 이승표

서울대학교 치과대학 구강해부학교실

본 연구는 미세전산화 단층촬영술을 이용하여 한국인의 상악제일대구치의 근관형태를 정량적으로 분석하고 해부학적 특징을 면밀하게 조사하는데 그 목적이 있었다.

상악제일대구치 53개를 미세전산화 단층촬영술 스캐너 (Skyscan1072, Skyscan b.v.b.a., Aartselaar, Belgium)를 이용하여 스캔하였고 개개 치아에 대한 1024 X 1024 화소와 19.5μm의 공간해상도를 가지는 502장의 횡단면상을 얻었으며, 삼차원 영상화 소프트웨어 (V-works 4.0, Cybermed Inc., Seoul, Korea)를 이용하여 근관에 대한 삼차원적 모델을 재구성 하였다. 삼차원으로 재구성된 모델을 이용하여 상악제일대구치의 근관의 형태를 Vertucci 방법으로 분류하였다. 또한 부근관의 위치의 평균값을 구하였다. 근심협측근관은 다양한 형태를 나타내었는데, Vertucci 분류의 유형 I이 15.1%, 유형 II가 7.5%, 유형 III이 7.5%, 유형 IV가 20.8%, 유형 V가 7.5%, 유형 VI이 26.4%, 유형 1-3-1이 3.8%, 유형 2-3이 9.4%, 유형 3-4가 1.9% 를 나타내었다. 부근관의 위치 (근단과 부근관 사이의 거리)는 근심협측근관이 1.36mm, 원심협측근관이 0.98mm, 구개측근관이 1.51mm 이었다.

본 연구는 기존의 연구에서 치아의 형태학적 특징을 연구하는 연구방법보다 많은 장점을 가지는 미세전산화 단층촬영술을 이용하여 상악제일대구치의 근관의 형태를 정량적으로 비교, 분석하였다. 그중에서 제일 중요한 점은 건전한 치아에서 얻은 자료들을 여러개의 단면에서 좀더 면밀히 평가, 분석할 수 있는 장점이 있다는 것이다. 한국인의 상악제일대구치의 근관의 형태를 미세전산화 단층촬영술과 삼차원 이미지 처리 소프트웨어를 이용하여 얻은 자료들은 동양인의 치아에 대한 좀더 많은 자료들을 제공할 것이다. 본 연구에서는 상악제일대구치의 근관의 형태를 분류하였으며, 부근관의 발현빈도와 발현 위치를 조사하였고, 이는 치근 절제술과 같은 임상술식시 기본적인 자료로 이용될 수 있으며, 근단 1/3 부위의 체감정도는 회전 전동 파일 시스템을 선택, 개발하는데 기본적인 지침이 될 수 있을 것이다. 근관의 원형정도는 근관확대와 근관충전시 중요한 고려사항이 될 수 있으며, 근관의 만곡형태는 근관치료기구의 진행방향에 도움이 될 수 있다. 결론적으로 이러한 결과들은 치과의사가 한국인 상악제일대구치의 근관치료를 수행함에 있어 도움을 줄 수 있다.

Key Word: 상악제일대구치, 근관형태, 삼차원 모델, 미세전산화 단층촬영술