Three-dimensional Analysis of Root Canal Curvature of Mandibular First Molars in a Korean Population Using Cone-beam Computed Tomography

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ABSTRACT

Introduction: The aim of this study was to investigate the three-dimensional characteristics of the mandibular first molar, especially canal curvature by using CBCT and three-dimensional modeling software.
Methods: CBCT images of 300 mandibular first molars were evaluated retrospectively from Korean 150 patients who visited the Yonsei Dental Hospital from August 2009 to July 2011. The central axis was defined from CBCT image using the V-Work software and reconstructed three-dimensional forms by Kappa program. The numbers and locations of curvatures in each canal of 109 mandibular first molars were recorded in Kappa program. Directions of curve (overall direction of canal, the direction of the first curve from orifice and the last direction of apical curve) were measured from occlusal view.
Results: All canals of mandibular first molars had more than 2.52 curvatures per each canal and almost all curvatures were measured over 25°. Overall canal direction of mandibular first molars proceeded mostly toward DB direction except DB canals of 3 root 4 canal teeth. MB and ML canal had first curve to mostly MB direction (54.0-82.6% of MB canals, 52.2-60.9% of ML canals) despite the general running direction through the apex toward the DB direction. Besides, MB and ML canals got severe curve angle by 28.5-40.6° below orifices.
Conclusions: More accurate understanding of three-dimensional root canal system's figuration is needed for prevention of errors in endodontic procedures and successful endodontic treatment.

Key words : Canal curvature, Cone-beam computed tomography, Mandibular first molar

INTRODUCTION

Comprehensive information of root canal anatomy is essential for successful endodontic treatment, which objective is to complete a thorough mechanical and chemical cleansing of the entire root canal system and its obturation with inert filling materials[1]. A part of the root canal system configuration with an important influence on instrumentation is the amount of canal curvature. No matter what was used between hand instrument and rotary system, instrumentation in the curved canal might give rise to serious technical errors as like ledge, stripped perforation, apical transportation, or file fracture[2,3].

The level of case difficulty increases with increasing degrees of root curvature[4]. American Association of Endodontists (AAE) developed guidelines for assessing endodontic case difficulty. The AAE Endodontic case difficulty Assessment Form enables a clinician to assign a level of difficulty to a particular case. According to these guidelines, the canals with 10-30° curvature are of moderate difficulty and those above 30° have high degrees of difficulty. Accurate information about the shape and curvature of root canals allows a clinician to give attention to instrument selection and instrumentation technique, and helps prevent possible problems.

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Root canal curvature can be assessed clinically from radiographs. Schneider was the first to measure curvature as the acute angle between the long axis of the canal and a line from the apical foramen to the point of initial curvature on radiographs in 1971[5]. Weine (1982) measured curvature by using the acute angle between lines passing through the apical and coronal portions[6]. Cunningham and Senia (1992) placed files in the mesial canals of extracted mandible molars[7] and Kartal and Cimilli (1997) studied canal curvature using reamers in mesial canals[8]. They reported that curves in the mesio-distal plane often are greater than those in the more readily accessible buccal-lingual plane. In addition to these angular measurements, Pruett et al. (1997) and Schafer et al. (2002) proposed the radius of curvature as a better method of description about abrupt curvature[2,9].

Aside from these two dimensional views of conventional radiographs, more recent research had reconstructed three dimension images from computed tomography images of teeth to investigate morphologic features. Micro-computed tomography has been used to analyze root canal configurations because of its high resolution and non-destruction of specimens in ex vivo studies[9-12]. Cone-beam computed tomography (CBCT) systems, too, are a practical tool for noninvasive and three-dimensional reconstruction imaging for uses in endodontic application and morphologic analyses. They are available for assessment of complex root canal anatomy and accurate three-dimensional relations between teeth and their surrounding skeletal structure in vivo.

The aim of this study was to investigate the 3 dimensional characteristics of the mandibular first molar in a Korean population, especially canal curvature by using CBCT and three-dimensional modeling software.

MATERIALS AND METHODS

Subjects

This study was approved by institutional Review Board of Yonsei Dental Hospital, Yonsei University, Seoul, Republic of Korea (IRB 2-2012-0017). Among the CBCT images of Korean patients who visited the Yonsei Dental Hospital from August 2009 to July 2011 for surgical removal of deeply impacted teeth (including third molars and supernumerary teeth), high quality CBCT images from 150 patients (81 men and 69 women) were screened, and images of 300 mandibular first molars were evaluated retrospectively. The mean age of the patients was 25.1 years of age, ranging from 20 to 45 years. Images of subjects who had mandibular first molars with completely formed apex and no previous endodontic treatment were selected for analysis.

CBCT in this study is Volux system (Genoray, Seongnam, Republic of Korea), scan setting is 85 kVp, 80 mA, 8.5 cm scan field, and voxel size is 0.167 mm^3. Tomography sections of 0.167 mm in the axial, coronal, and sagittal planes were created. The data were exported into DICOM (Digital Imaging and Communications in Medicine) file format.

Image analysis

We investigated the number of roots and canals of 300 mandibular first molar on the right and left sides by observing CBCT images.

For the analysis of root canal curvatures, 109 right mandibular fist molars were included except teeth with 2 root canals (mesial 1 canal and distal 1 canal) or complex isthmus communications which made difficulty in canal distinction. Two dentists separately evaluated each image twice. In cases of disagreement, they came to consensus by discussion. The central axis was determined for each canal and its curvature calculated as previously described[13,14]. This central axis was defined using the V-Works software program (V-works 4.0, Cybermed Inc. Seoul, Korea) (Fig 1)[13]. In each canal, 10-20 image slices were selected to adequately span the entire length. On each slice, major and minor axes were plotted manually, and their points of intersection were connected to create a central axis. Kappa software developed specifically for the study imported the central axis of each canal from the V-Works program and then reconstructed the central axis of the canal into three-dimensions (Fig 2). The numbers and locations of curvatures of each canal were recorded while being rotated by Kappa program. In the Kappa program a tangential circle ran on the central axis and changed in size by severity of the curvature at that point. We determined the number of curves and the location of the curve in each canal by the change of circle size and direction. Basically the study used Schneider method, but if there was more than one curve, Cunningham and Senia method was used to measure curve angle. Vista metrix 1.36 software was used when we measured the angle of canals (Fig 2). For investigation of location of canal curvature, we divided equally each canal into seven parts in Kappa program. Each 7 parts were defined as CC, C, CM, M, MA, A, and AA in the order of location from orifice to apex (Fig 3).

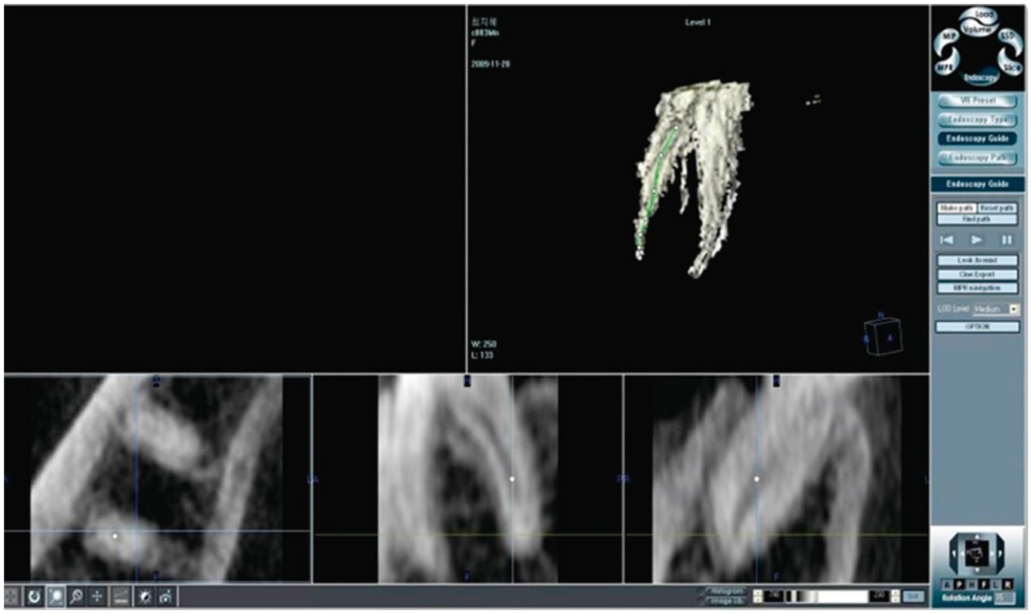

Figure 1. *We sliced CT images into 15-20 slices and decided central axis using V-works program.*

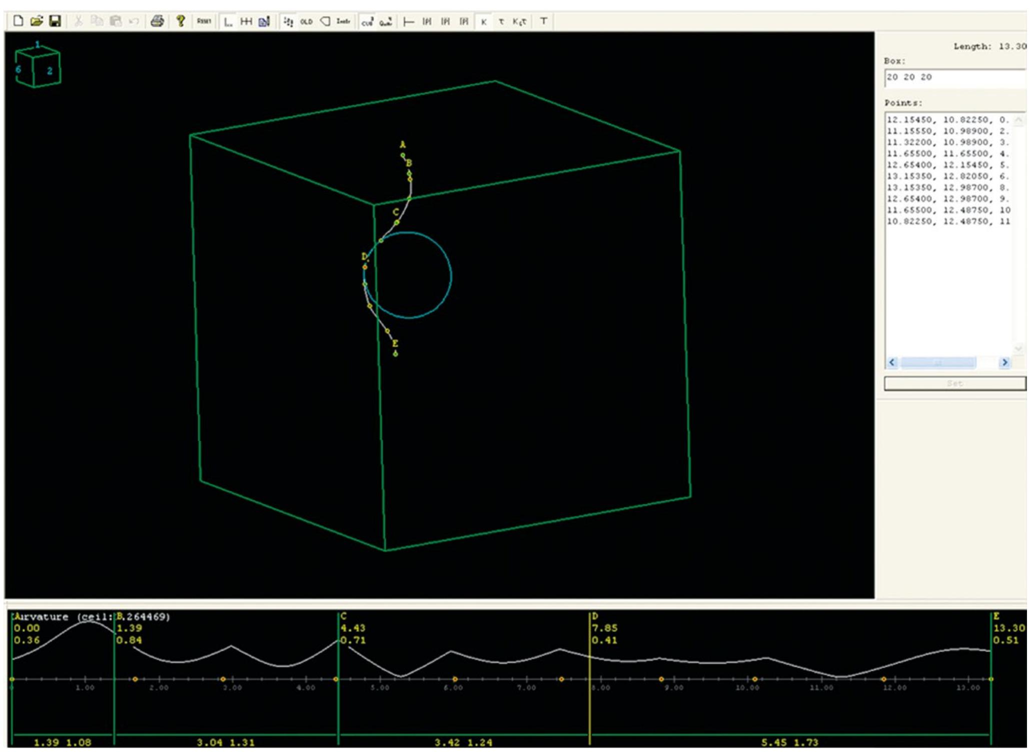

Figure 2. *Kappa software reconstructed the central axis to three-dimensions from data of V-work software. The angle of curvature at the point which has the smallest tangential circle was measured using Vista metrix program in Schneider method.*

Direction of curve was measured from occlusal view of same teeth. First, the overall direction of canal was observed from orifice to apex, and then the direction of the first curve from orifice, finally the last direction of apical curve was observed (Fig 4).

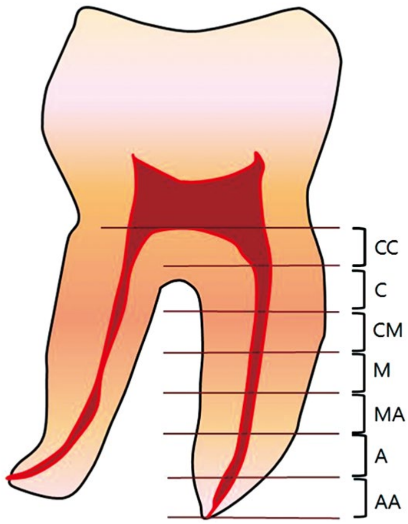

Figure 3. The canals were divided equally into 7 parts by using Kappa program.

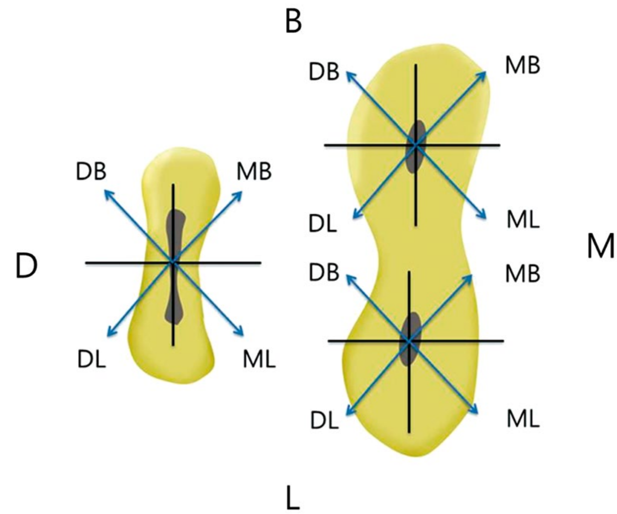

Figure 4. Notational system of canal's running direction.

Table 1. Incidence of [2R2C], [2R3C], [2R4C] and [3R4C]

	Right	Left	Total n (%)	p-value*
2R2C	5	5	10 (3.3%)	1
2R3C	88	101	189 (63%)	0.3443
2R4C	19	13	32 (10.7%)	0.2888
3R4C	38	31	69 (23%)	0.3994
Total	150	150	300 (100%)	

p-value* chi-square test. Statistical significance was set at $p<0.05$

Statistical analysis

Statistically significant differences of canal configuration between right and left side and curve direction per each canal were evaluated by chi-square test using SPSS software (Version 18.0; SPSS, Inc, Chicago, IL). Statistical significance was set at $p<0.05$.

RESULT

Canal configuration

Classification of numbers of Roots and Canals is described in Table 1. Mandibular first molars with 3 roots 4 canals were 23 percent of samples, showing right side dominance. No significant statistical difference was detected between right and left side in any groups (Table 1).

The frequency and degree of canal curvature

2 roots 2 canals first molars [2R2C] were excluded while measuring degree of curve and direction. The 63 2 roots 3 canals molars [2R3C] and 23 2 roots 4 canals [2R4C], and 23 3 roots 4 canals [3R4C] were included in this study. Total 109 teeth didn't have complex isthmus communications which made difficulty in canal distinction.

The frequency and degree of canal curvatures are described in Table 2. Average number of curves is 3.1 on MB canal on [2R3C] teeth. The curve is found most commonly in M and A portion (57.1%). Average angle of curvature on AA portion was 33.6°, larger than that on CC which was 33.1°. M portion showed curves most commonly in the ML canal (68.3%), while the AA portion showed the largest curve angle of 33.7°. Distal canal had average number of 2.5 curves and the curvature degree of each place of AA, A portion showed 29.9°, 27.0° of the most severe curvature (Table 2).

MB canal of [2R4C] teeth had average of 3 curves. The frequency of curves is highest in M portion (47.8%). CC part showed the most severe curvature of 40.6°, followed by CM part of 39°. ML canal had average number of 3.4 curves. M and CM part had the most common curve (52.2%) but CC part had the most severe curvature of 34°. DB canal had average of 3.3 curves. AA part had the most common curve also (52.2%). On the other hand, C part had the most severe curvature by 37.6°. DL canal also had the most common curve on CC part (43.5%) with the most severe curvature by 40.2°.

There was an average of 3.3 curves seen from MB canal of [3R4C] teeth. Curves were found most commonly in the

Table 2. *Curvature degree, location and incidence of curvatures in [2R3C], [2R4C] and [3R4C]*

[2R3C]

Canal	Curve	Location							Number of curves (mean ± SD)
		CC	C	CM	M	MA	A	AA	
MB	Incidence x/n (%)*	33/63 (52.4%)	16/63 (25.4%)	23/63 (36.5%)	36/63 (57.1%)	22/63 (34.9%)	36/63 (57.1%)	35/63 (55.6%)	3.1 ± 1.01
	Degree Mean ± SD	33.1 ± 10.4	32.1 ± 11.7	28.7 ± 8.5	25.3 ± 8.2	26.2 ± 9.1	28.5 ± 12.3	33.6 ± 10.1	
ML	Incidence x/n (%)	30/63 (47.6%)	20/63 (31.7%)	18/63 (28.6%)	43/63 (68.3%)	28/63 (44.4%)	22/63 (34.9%)	26/63 (41.3%)	3.0 ± 1.0
	Degree Mean ± SD	31.0 ± 14.5	26.9 ± 7.9	31.3 ± 12.8	29.4 ± 10.3	29.6 ± 13.4	32.3 ± 15.6	33.7 ± 15.6	
D	Incidence x/n (%)	24/63 (38.1%)	7/63 (11.1%)	21/63 (33.3%)	28/63 (44.4%)	16/63 (25.4%)	33/63 (52.4%)	32/63 (50.8%)	2.53 ± 1.1
	Degree Mean ± SD	27.5 ± 9.9	26.0 ± 8.9	23.9 ± 8.3	24.0 ± 10.0	21.6 ± 9.3	27.0 ± 10.3	29.9 ± 8.6	

[2R4C]

Canal	Curve	Location							Number of curves (mean ± SD)
		CC	C	CM	M	MA	A	AA	
MB	Incidence x/n (%)	9/23 (39.1%)	5/23 (21.7%)	4/23 (17.4%)	11/23 (47.8%)	7/23 (30.4%)	8/23 (34.8%)	9/23(39.1%)	3.0 ± 1.2
	Degree Mean ± SD	40.6 ± 8.3	36.2 ± 19.7	39.0 ± 17.5	33.1 ± 13.5	27.6 ± 11.8	23.9 ± 6.6	33.6 ± 10.4	
ML	Incidence x/n (%)	7/23 (30.4%)	8/23 (34.8%)	12/23 (52.2%)	12/23 (52.2%)	8/23 (34.8%)	8/23 (34.8%)	6/23 (26.1%)	3.4 ± 0.7
	Degree Mean ± SD	34.0 ± 5.1	27.5 ± 7.3	25.2 ± 6.8	29.4 ± 9.8	27.0 ± 5.9	31.5 ± 11.74	33.7 ± 9.6	
DB	Incidence x/n (%)	7/23 (30.4%)	5/23 (21.7%)	9/23(39.1%)	9/23(39.1%)	5/23 (21.7%)	6/23 (26.1%)	12/23 (52.2%)	3.3 ± 0.7
	Degree Mean ± SD	29.4 ± 6.8	37.6 ± 17.9	27.2 ± 7.9	28.2 ± 9.6	31.6 ± 11.1	23.0 ± 8.9	35.6 ± 6.8	
DL	Incidence x/n (%)	10/23 (43.5%)	5/23 (21.7%)	1/23 (4.3%)	6/23 (26.1%)	5/23 (21.7%)	4/23 (17.4%)	3/23 (13.0%)	3.1 ± 1.0
	Degree Mean ± SD	40.2 ± 11.3	26.2 ± 3.6	32.3 ± 15.6	34.7 ± 10.0	37.9 ± 5.6	31.8 ± 13.5	39.0 ± 13.4	

[3R4C]

Canal	Curve	Location							Number of curves (mean ± SD)
		CC	C	CM	M	MA	A	AA	
MB	Incidence x/n (%)	10/23 (43.5%)	7/23 (30.4%)	6/23 (26.1%)	15/23 (65.2%)	10/23 (43.5%)	16/23 (69.6%)	20/23 (87%)	3.3 ± 1.0
	Degree Mean ± SD	30.9 ± 10.8	19 ± 8.5	25.5 ± 7.8	23.1 ± 10.7	26.3 ± 9.3	27.8 ± 10.9	28.1 ± 9.8	
ML	Incidence x/n (%)	10/23 (43.5%)	5/23 (21.7%)	8/23 (34.8%)	16/23 (69.6%)	5/23 (21.7%)	12/23 (52.2%)	8/23 (34.8%)	2.8 ± 0.9
	Degree Mean ± SD	28.5 ± 8.6	26.4 ± 12.3	24.3 ± 5.7	22.9 ± 8.9	30.8 ± 7.3	28.8 ± 11.7	30.5 ± 11.9	
DB	Incidence x/n (%)	7/23 (30.4%)	5/23 (21.7%)	4/23 (17.4%)	13/23 (56.5%)	10/23 (43.5%)	8/23 (34.8%)	9/23(39.1%)	2.52 ± 1.1
	Degree Mean ± SD	40.7 ± 20.0	29.2 ± 8.9	14.8 ± 7.9	22.8 ± 9.9	17.9 ± 10.0	22.8 ± 5.1	30.7 ± 10.8	
DL	Incidence x/n (%)	12/23 (52.2%)	7/23 (30.4%)	10/23 (43.5%)	11/23 (47.8%)	8/23 (34.8%)	9/23(39.1%)	13/23 (56.5%)	3.1 ± 1.0
	Degree Mean ± SD	38.3 ± 13.2	32.4 ± 12.4	29.3 ± 10.2	29.1 ± 16.3	35.1 ± 8.0	32.3 ± 8.7	28.4 ± 11.7	

*x/n = the number of tooth which has curvature in this location/total number of teeth

AA portion (87%) followed by A (69.6%). Average angle of curvature seen from each part was largest on CC by 30.9°. The ML canal had the most curves on the M part (69.6%). The MA and AA parts each had curvature of 30.8°, 30.5°. There was average number of 2.5 curves seen in the DB canal on [3R4C] tooth. Curves were most common in M (56.5%), and the CC part had the most severe curvature by 40.7°. The DL canal had average of 3.1 curves. The AA part had the most frequent curve (56.5%) followed by the CC part with the most severe curvature by 38.3°.

Direction of canal curvature

Direction of canal curvature was investigated by classifying the first curve direction, apex curve direction, and general running direction into MB, ML, DB, DL direction of the same 109 teeth. They were calculated in percentage per each direction. Statistically significant differences of all curve direction as per each canal were detected ($p < 0.05$) (Table 3).

All canals in [2R3C] teeth proceeded to DB direction in general (68.3% of MB canal, 61.9% of ML canal, 100% distal canal). Apex curve proceeded mostly to DB direction in ML and distal canals (both 65.1%). But MB canal proceeded mostly to DL direction (42.9%) and DB direction (41.3%). D canal had first curve direction to DB by 84.1%, while MB, ML canal proceeded to MB direction by MB canal 54.0% and ML canal 57.1% (Fig 5).

Overall canal direction of [2R4C] proceeded to DB direction in general (MB canal 65.2%, ML canal 73.9%, DB canal 91.3% and DL canal 73.9%). The first curve of MB, and ML canals ran mostly into the MB direction (MB canal 82.6%, ML canal 52.2%), but most DB, DL canals had first curve direction toward DB direction (DB canal 65.2%, DL canal 52.2%). Apical curve ran mostly to DB direction by MB canal 52.2%, ML canal 82.6%, DB canal 47.8%, and DL canal 56.5% (Fig 6).

Overall canal direction of [3R4C] proceeded toward DB direction in MB, ML canal (MB canal 73.9%, ML canal 60.9%) and DL direction of DB canal 100%, and DB direction of DL canal 52.2% were shown. Similar to [2R4C] teeth, MB and ML canal had first curve direction to MB direction mostly (both 60.9%). While, DB and DL canal proceeded to DB mostly (DB canal 87.0%, DL canal 52.2%). Most apical curves tend to be out toward DB direction (MB canal 47.8%, ML canal 69.6%, DB canal 65.2%, and DL canal 52.2%) (Fig 7).

DISCUSSION

In this study mandibular first molars which had a separated DL root formed 23% of all cases. Extra disto-lingual roots[15] called Radix entomolaries were commonly found in mandibular first molar as mongoloid traits[16-20]. The previous studies showed DL root incidence of Caucasian (4.3%)[21], Burmese (10%)[22], Eskimo (21.7%)[23], Chinese (15-33.3%)[16,17,20,24], Japanese (22.7%)[25], Korean (24.5%)[26].

4 canals at the right side formed 38% of all cases, and the left side formed 29.3%. 4 canals occurred more frequently on the right side. This is similar to previous many studies[20,26,27] which showed higher rates toward the right side. The frequency of 3 root existence at right side in Song's study (2010) was higher than that of left side, but it did not show a significant difference[28]. Likewise in this study, the first molars which had 4 canals were found at the right side more than at the left side but no significant difference was found between right and left side ($p > .05$).

According to the past studies like Schneider's, the number of curves was mostly 1 or 2. But in this study observing canals in 3-dimensionally, every canal had more than 2 curves. The degree of curvature of this study was more severe than that of past studies observing canals 2-dimensionally in clinical view (bucco-lingual view) and proximal view (mesio-distal view). The study by Cunningham (1992) reported that MB canal had 16.5° and ML canal had 19.4° in clinical view, but MB had 26.7° and ML canal had 23.5° in a proximal view about the curve angle[7]. Chen (2009) reported that DL root in proximal view got 36.5° which was much steeper than that of in clinical view[29]. Recently Gu et al. (2010) reported that MB canal got 24.34°, ML canal got 22.39°, DB 13.71° and DL 13.81° in clinical view, but DB canal got 16.6° and DL canal got 36.6° in proximal view[30]. Comparing our results to these data, the mean of the steepest angles of [3R4C], MB 30.9°, ML 30.8°, DB 40.7° and DL 38.3°, were severe curvature over 25° at the point of Schneider's criteria. This may represent the limit of 2-dimensional measuring method, because root canals always run 3-dimensionally (Fig 8).

After coronal flaring and inserting files, the existing curve measuring method 2-dimensionally in Schneider's also would make errors, recording a gentler angle because of the straightening tendency of the curved file. A new method of deciding the main axis which is not actually straight at any point and measuring three-dimensional angles is needed to understand original canal shape in observing original canal

Table 3. Canal overall direction, 1st curve running direction, apical curve direction and in [2R3C], [2R4C] and [3R4C]

[2R3C]

Canal	Canal direction	Overall	Direction n %	1st curve	Direction n %	Apical curve	Direction n %
MB	MB	10	15.9%	34	54.0%	5	7.9%
	ML	3	4.8%	12	19.0%	5	7.9%
	DB	43	68.3%	14	22.2%	26	41.3%
	DL	7	11.1%	3	4.8%	27	42.9%
ML	MB	22	34.9%	36	57.1%	12	19.0%
	ML	0	0.0%	15	23.8%	0	0.0%
	DB	39	61.9%	10	15.9%	41	65.1%
	DL	2	3.2%	2	3.2%	10	15.9%
D	MB	0	0.0%	3	4.8%	8	12.7%
	ML	0	0.0%	0	0.0%	5	7.9%
	DB	63	100.0%	53	84.1%	41	65.1%
	DL	0	0.0%	7	11.1%	9	14.3%

[2R4C]

Canal	Canal direction	Overall	Direction n %	1st curve	Direction n %	Apical curve	Direction n %
MB	MB	4	17.4%	19	82.6%	0	0.0%
	ML	3	13.0%	3	13.0%	4	17.4%
	DB	15	65.2%	1	4.3%	12	52.2%
	DL	1	4.3%	0	0.0%	7	30.4%
ML	MB	6	26.1%	12	52.2%	1	4.3%
	ML	0	0.0%	9	39.1%	1	4.3%
	DB	17	73.9%	2	8.7%	19	82.6%
	DL	0	0.0%	0	0.0%	2	8.7%
DB	MB	0	0.0%	1	4.3%	2	8.7%
	ML	0	0.0%	0	0.0%	3	13.0%
	DB	21	91.3%	15	65.2%	11	47.8%
	DL	2	8.7%	7	30.4%	7	30.4%
DL	MB	0	0.0%	2	8.7%	1	4.3%
	ML	0	0.0%	1	4.3%	3	13.0%
	DB	17	73.9%	12	52.2%	13	56.5%
	DL	6	26.1%	8	34.8%	6	26.1%

[3R4C]

Canal	Canal direction	Overall	Direction n %	1st curve	Direction n %	Apical curve	Direction n %
MB	MB	4	17.4%	14	60.9%	4	17.4%
	ML	0	0.0%	3	13.0%	1	4.3%
	DB	17	73.9%	3	13.0%	11	47.8%
	DL	2	8.7%	3	13.0%	7	30.4%
ML	MB	9	39.1%	14	60.9%	4	17.4%
	ML	0	0.0%	3	13.0%	0	0.0%
	DB	14	60.9%	4	17.4%	16	69.6%
	DL	0	0.0%	2	8.7%	3	13.0%
DB	MB	0	0.0%	1	4.3%	3	13.0%
	ML	0	0.0%	0	0.0%	1	4.3%
	DB	0	0.0%	20	87.0%	15	65.2%
	DL	23	100.0%	2	8.7%	4	17.4%
DL	MB	0	0.0%	2	8.7%	2	8.7%
	ML	0	0.0%	0	0.0%	0	0.0%
	DB	12	52.2%	12	52.2%	12	52.2%
	DL	11	47.8%	9	39.1%	9	39.1%

Overall Canal direction, 1st curve direction and apical curve direction had significant differences ($P < 0.05$)

curvatures.

Existence of 2 or more severely angled curves means that the cutting vector made by the spreading nature of the file can make trouble for not conforming to the canal's original shape while performing canal instrumentation. This is the cause of canal transportation. When the vector of general file force is aligned opposite to general canal direction, strip perforation might occur. In this study, 1st curve of coronal

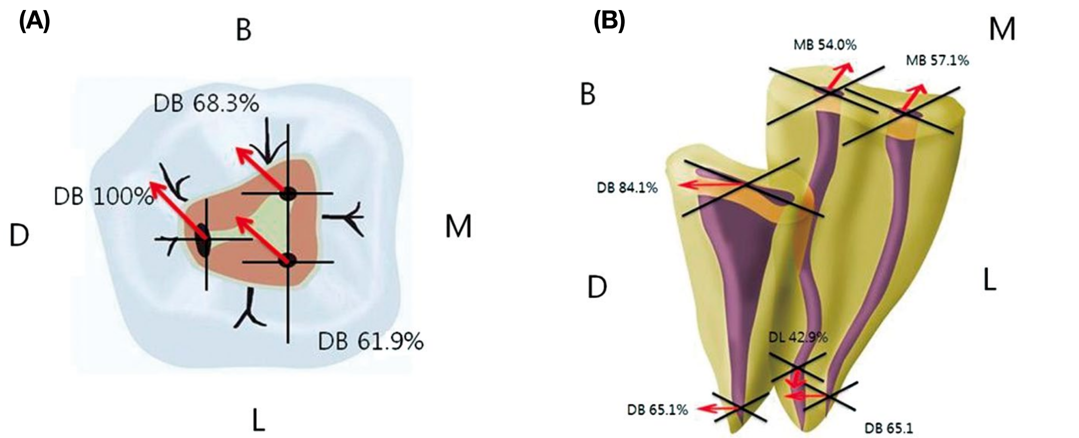

Figure 5. *(A) The common example of overall canal direction of [2R3C] from orifice to apex; (B) 1st curve, apical curve direction of [2R3C] tooth.*

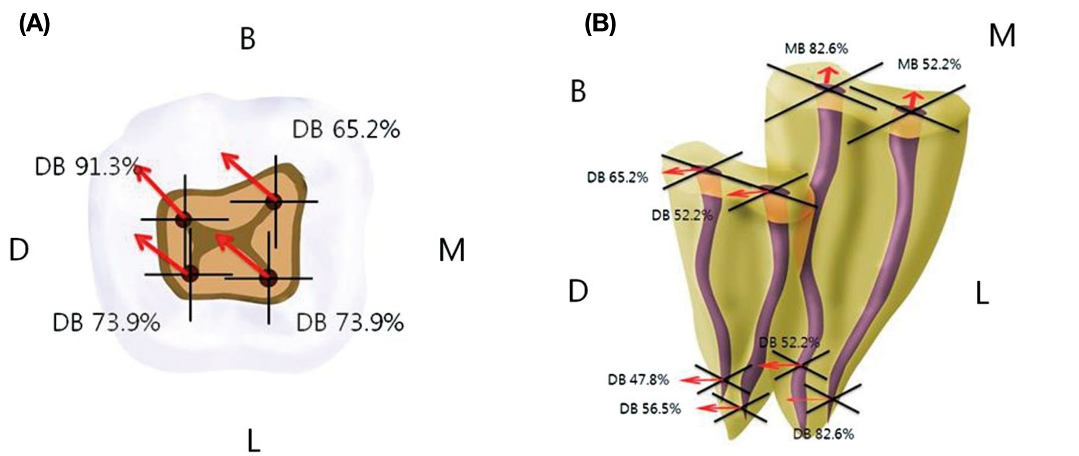

Figure 6. *(A) The common example of overall canal direction from orifice to apex of [2R4C] teeth; (B) 1st curve, apical curve direction of [2R4C] teeth.*

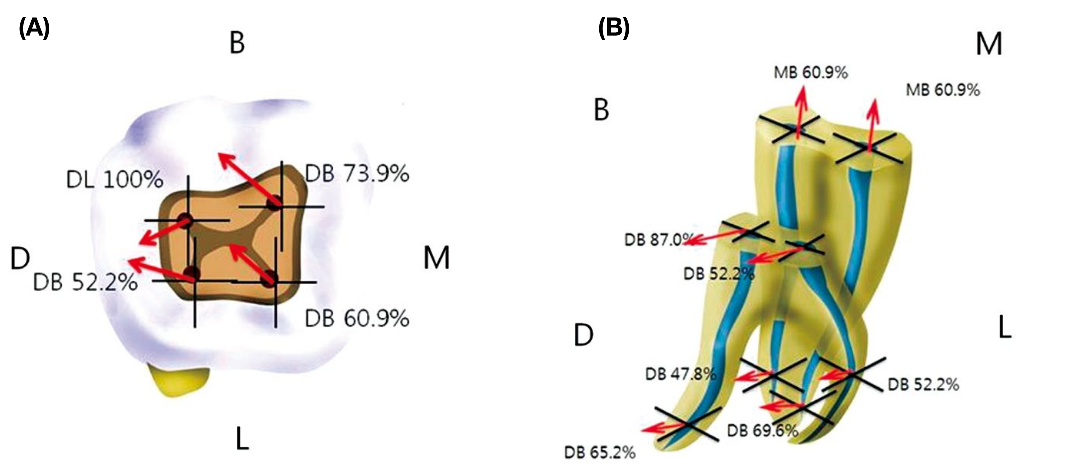

Figure 7. *(A) The common example of overall canal direction of [3R4C] teeth; (B) 1st curve, apical curve direction of [3R4C] teeth.*

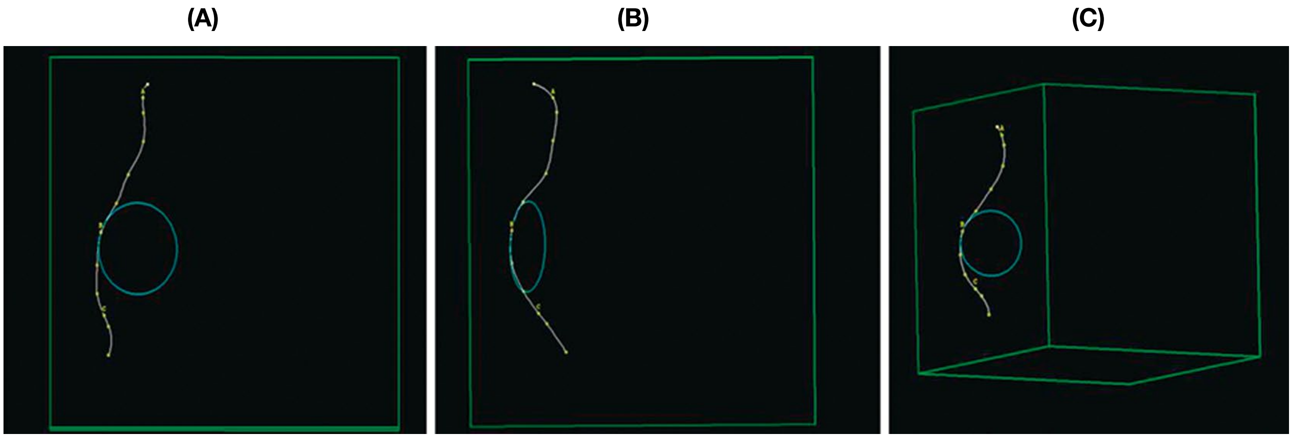

Figure 8. (A) Canal curvature in bucco-lingual view (clinical view); (B) Canal curvature in mesio-distal view of the same canal (proximal view); (C) Canal curvature in 3 dimensional view of the same canal.

part proceeded to MB direction in MB and ML canals by 52.2-82.6% of all. On the other hand, the general running direction of them till passing through the apex was the DB direction by 60.9-73.9%. In addition, the file approach was more difficult in MB and ML canals than in the distal canal, because of its severe curve angle by 28.5-40.6° and inconvenient file-inserted path from back. Therefore more caution and initial coronal flaring should be needed to prevent dangerous zone's strip perforation toward the furcation area of MB and ML canals.

We found that most root canals (except DB canal of [3R4C]) run toward DB direction, and there are a considerable number of canals (41.3-82.6%) which front on the DB around apex. This means that actual mandibular molar's mesio-lingual tilting pattern may exaggerate apical swing toward DB direction of all canal itself. It is important to understand the root canal's direction inside the mandible, especially if we can't recognize the original crown shape due to crown restoration or severe attrition of overall teeth.

In the case of MB and ML canals, the middle portion had the most curves. While distal 1 canal molars have more severe curves in apical area, distal 2 canal molars have more severe curves below the orifice. It was supposed that curve frequency and degree of angle would be associated with root's divergency around furcation.

This study made use of CBCT to examine mandibular first molar's three dimensional canal configurations. Understanding the exact configurations and curvatures of canal rather than those of root will support appropriate direction of file inserting or performing instrumentation in root canal treatment. Furthermore, by using CBCT, canal direction inside the mandible can be described. This is useful for predicting canal direction of a tooth which doesn't have its original crown shape. The result of this study made it possible to find out much more information than from the 2 dimensional clinical view or proximal view. We realized the frequency of curves and existence of more severe curvatures than had been known in the past. Clinicians should be able to recognize 3 dimensional root canal system's anatomy appropriately, choose right treatment plan and properly interpret prognosis. The importance of coronal flaring to prevent canal transportation while performing mechanical instrumentation has been mentioned in the previous studies and emphasized again in this study. Importance of preparation of apical abrupt curvature was emphasized also. This study used Schneider method to help the clinician understand the degree of curve in general. But other than currently established method, the new method which can measure curved angle on 3 dimensional curves quantitatively accurate is required. Endodontic case difficulty in point of curvature should be mentioned again according to this new method.

CONCLUSION

Canal curvature is closely related to endodontic case difficulty assessment. We examined especially canal curvature of the mandibular first molar in a Korean population by using CBCT and 3-dimensional modeling software program. We realized that all canals have more curves in each canal and more severe curvatures than had been known in the past. The result of this study presented more valuable information about root canal curvatures and curve directions than any other previous data using 2 dimensional clinical view or proximal view. More accurate understanding of three-dimensional root canal system's figuration should be required for prevention of errors in endodontic procedures and successful endodontic treatment.

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