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Cone-beam computed tomography for the assessment of root–crown ratios of the maxillary and mandibular incisors in a Korean population

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Objective: This retrospective, cross-sectional study aimed to establish reference data for normal crown and root lengths and the root–crown ratios (R/C ratios) for the mature maxillary and mandibular incisors in a Korean population by using cone-beam computed tomography (CBCT). **Methods:** We included 672 Korean patients (141 men and 531 women; mean age, 27.2 ± 7.7 years) who underwent CBCT examinations during various dental treatments. Crown and root lengths and the R/C ratios of the maxillary and mandibular incisors were measured using CBCT data, which were analyzed to detect significant differences between demographic factors as well as sagittal and vertical skeletal or occlusal relationships. **Results:** Teeth of the same type in each half-arch were symmetrical. The mean R/C ratios varied from 1.1 to 1.2 for the maxillary incisors and from 1.3 to 1.4 for the mandibular incisors. Crown and root lengths were greater in men than in women, regardless of tooth type. Root lengths and R/C ratios for the mandibular incisors were significantly greater in patients with skeletal Class II malocclusion or an excessive overjet than in the other patients. The R/C ratios for the mandibular incisors were lower in patients with an open bite than in those with a normal or deep bite. Moreover, the R/C ratios for the mandibular incisors increased with age. **Conclusions:** The data obtained in our study can serve as reference values for crown and root lengths and the R/C ratios for the maxillary and mandibular incisors in the Korean population.
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Key words: Tooth crown, Tooth root, Incisor, Cone-beam computed tomography, Population

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INTRODUCTION

Unfavorable root–crown ratios (R/C ratios) for the maxillary and mandibular incisors can affect the prognosis of various dental treatments. Previous studies have shown that the maxillary and mandibular incisors are the most susceptible to external apical root resorption during orthodontic treatment.[1-3] Several factors are known to contribute to root resorption in the anterior teeth, including ethnic differences, abnormal root shape (blunt or pipette), and an excessive overjet requiring extraction treatment and a longer treatment duration.[4,5] In a study on a Brazilian population, Marques et al.[6] used periapical radiography to determine that root resorption before treatment was associated with a high risk of severe root resorption during orthodontic treatment.

To date, most data on normal R/C ratios have been obtained using periapical or panoramic radiographs. Hölttä et al.[7] evaluated a Finnish population by using panoramic radiographs and reported that the mean R/C ratios for the maxillary central incisors in men and women were 1.86 ± 0.17 and 1.78 ± 0.16, respectively, according to Lind's method.[8,9] By using the same method, Yun et al.[9] evaluated 99 Korean young adults and reported that the mean R/C ratios for the maxillary and mandibular central incisors were 1.49 ± 0.20 and 1.53 ± 0.24, respectively. Panoramic radiographs can be easily acquired in dental clinics without significant errors, and exhibit an acceptable reproducibility under low radiation exposure.[7,9] However, some previous studies have shown that measurements of the maxillary and mandibular central incisors on panoramic radiographs have the lowest reliability among assessments of all tooth types.[10,11] In addition, identification of the cementoenamel junction (CEJ) on periapical radiographs acquired using the paralleling technique can be affected by angular differences between the concerned tooth and the film.[12]

Although cone-beam computed tomography (CBCT) requires high radiation dosages and is relatively expensive, it has gained widespread acceptance in the field of dentistry, because distortion-free slice images of single roots are excellent for measuring the crown and root lengths of anterior teeth.[10,13] Kim et al.[14] reported that, although CBCT-based measurements showed a wider range of agreement limits for root lengths than for crown lengths, they could be used as references for evaluating incisor, canine, and premolar root lengths in 62 Korean patients with malocclusion. However, because of the small sample size of that study, the findings cannot be generalized to larger populations.

The aim of this retrospective, cross-sectional study was to establish reference data for normal crown and root lengths and the R/C ratios for the maxillary and mandibular incisors with complete root formation in a Korean population by using CBCT. The specific aim was to detect significant differences in CBCT measurements between demographic factors (sex and age) as well as sagittal and vertical skeletal or occlusal relationships.

MATERIALS AND METHODS

Subjects

From 1999 to 2014, 1,217 patients visited a private clinic in Seongnam, Korea, to undergo a variety of dental treatments. In this retrospective, cross-sectional study, we evaluated existing CBCT data for 672 of these 1,217 adults, who met the following inclusion criteria: age ≥ 18 years; little residual skeletal growth and complete root formation in most teeth; no severe craniofacial deformities such as cleft lip and/or palate; no loss of one or more permanent anterior teeth; no history of orthodontic treatment and/or orthognathic surgery; no systemic diseases such as hypothyroidism, Down syndrome, and Turner syndrome; no periodontal diseases, as indicated by a community periodontal index score of 3 or more; no restorations that altered the incisal edges; and no history of trauma, severe attrition, and/or occlusal adjustment. The sex and age of each patient was recorded, and the sagittal relationship was classified as skeletal Class I, Class II, and Class III according to the ANB (point A, nasion, point B) angle: skeletal Class I, 0°–4°; skeletal Class II, > 4°; and skeletal Class III, < 0°. The overjet was classified as follows: normal, 0–4 mm; excessive, > 4 mm; and cross bite, < 0 mm. The overbite was classified as follows: normal, 0–4 mm; deep bite, > 4 mm; and open bite, < 0 mm.

The study protocol conformed to the guidelines of the Declaration of Helsinki and was approved by the Institutional Review Board of the Ministry of Health and Welfare, Korea (IRB No. P01-201601-21-001). Informed consent was obtained from all individual participants included in this study.

Methods

CBCT images were acquired with the subjects in a standard upright position (scanning time, 95 s; field of view, 10 × 8.5 cm; tube voltage, 50–99 kVP; tube current, 4–16.0 mA; and voxel size, 0.2–0.3, based on the patient's size) on the scanning device (PaX-i3D Smart; Vatech Co., Hwaseong, Korea). The acquired data were exported in the Digital Imaging and Communications in Medicine (DICOM) multifile format into a three-dimensional image analysis software (Ez3D2009; Ewoosoft, Co., Ltd., Hwaseong, Korea).

One trained examiner measured all crown and root lengths along the axes of the eight maxillary and

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mandibular incisors by using a reference line from the labial and palatal CEJ to the incisal tip and root apex on sagittal views (Figure 1). Reproducibility was determined by comparing measurements obtained through original examinations with those obtained through repeated examinations. Measurements for 110 randomly selected patients were repeated by the same examiner after 2 weeks. The method error was calculated using Dahlberg's formula. Errors ranged from 0.09 to 0.13 mm for linear measurements; these were minor and not statistically significant.

Statistical analysis

All statistical analyses were performed using SPSS version 21.0 (IBM Korea Inc., Seoul, Korea). The Kolmogorov-Smirnov test was used to verify the normality of data distribution. Since the data were not normally distributed, nonparametric tests were used. Descriptive statistics, including means and standard deviations, were used to describe each variable analyzed in the study. For comparison of CBCT measurements between the right and left sides, intraclass correlation coefficients (ICCs) were determined and assessed.

The Mann-Whitney *U*-test was applied to detect statistically significant differences in the CBCT measurements according to sex, whereas the Kruskal-Wallis test was applied to detect significant differences in the measurements according to skeletal classification, overjet, or overbite. Spearman rank correlation coefficients were used to explore the correlations between the CBCT measurements for the maxillary and mandibular incisors and age. With regard to the strength of the correlations, $r > 0.40$ was considered to represent a moderate-to-strong correlation and $r < 0.40$ was considered to represent a weak correlation. A p-value of < 0.05 was considered statistically significant.

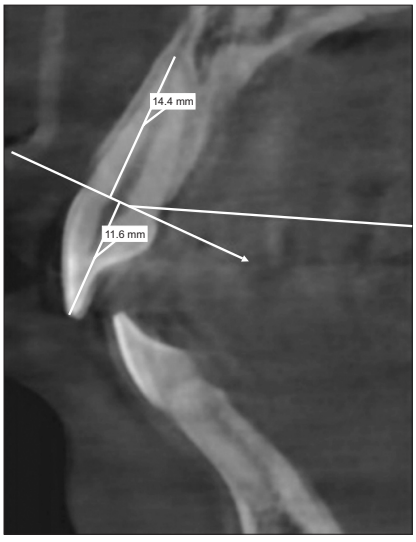

Figure 1. Measurements of crown and root lengths on sagittal cone-beam computed tomography images acquired for a Korean population. Measurements for the eight maxillary and mandibular incisors are made along the tooth axes by using a reference line from the labial and palatal cementoenamel junction to the incisal tip and root apex.

RESULTS

Complete data were recorded for 672 adults with a mean age of 27.2 ± 7.7 years. The sex distribution was not even (531 women, 79.0%; Table 1). The number of patients with skeletal Class I, Class II, and Class III malocclusions were 235 (35.0%), 393 (58.5%), and 44 (6.5%), respectively. The number of patients who exhibited an excessive overjet, a deep bite, and an open

Table 1. Sample characteristics (n = 672)

Variable	Data
Sex	
Men	141 (21.0)
Women	531 (79.0)
Age (yr)	27.2 ± 7.7
Skeletal Classification	
Class I	235 (35.0)
Class II	393 (58.5)
Class III	44 (6.5)
Overjet	
Normal overjet (0–4 mm)	399 (59.4)
Excessive overjet (> 4 mm)	254 (37.8)
Cross bite (< 0 mm)	19 (2.8)
Overbite	
Normal overbite (0–4 mm)	511 (76.0)
Deep bite (> 4 mm)	125 (18.6)
Open bite (< 0 mm)	36 (5.4)

Values are presented as number (%) or mean ± standard deviation.

Table 2. Intraclass correlation coefficients for the same type of teeth on the left and right sides (n = 672)

Variable	Crown length	Root length
Maxillary right and left central	0.86	0.92
Maxillary right and left lateral	0.85	0.88
Mandibular right and left central	0.85	0.86
Mandibular right and left lateral	0.87	0.85

bite were 254 (37.8%), 125 (18.6%), and 36 (5.4%), respectively. The ICC values were greater than 0.85 (range, 0.85 to 0.92) for all tooth pairs in the maxilla and mandible, indicating that the same type of teeth in each half-arch were symmetrical (Table 2).

The mean crown and root lengths for the maxillary central incisors were 10.9 ± 0.8 mm (range, 8.6 to 13.8 mm) and 11.9 ± 1.5 mm (range, 6.7 to 16.5 mm), respectively (Table 3). The R/C ratios were lower for the maxillary central incisors (1.1 ± 0.2) than for the maxillary lateral incisors (1.2 ± 0.1). The mean crown and root lengths for the mandibular central incisors were 8.6 ± 0.7 mm (range, 6.3 to 10.5 mm) and 11.0 ± 1.0 mm (range, 6.5 to 15.3 mm), respectively. The R/C ratios were lower for the mandibular central incisors (1.3 ± 0.1) than for the mandibular lateral incisors (1.4 ± 0.1).

When the mean crown and root lengths for the two tooth groups in both arches were compared between men and women, both measurements were higher for men than for women ($p < 0.001$; Table 4). The R/C ratios for the maxillary lateral incisors showed no significant difference between the sexes, whereas those for the mandibular central incisors were greater in men than in women ($p = 0.001$).

The mean root lengths for the two tooth groups in both arches were greater in patients with skeletal Class II malocclusion than in those with skeletal Class I or Class III malocclusion (Table 5). Moreover, the R/C ratios for the mandibular incisors were significantly greater in patients with skeletal Class II malocclusion than in patients with skeletal Class I or Class III malocclusion ($p < 0.05$). Similar to the results shown in Table 4, the mean root lengths and R/C ratios for the mandibular incisors were significantly greater in patients with an excessive overjet than in those with a normal overjet or a cross bite (Table 6).

The mean crown lengths for the maxillary incisors and the mean root lengths for the mandibular incisors were greater in patients with a deep bite than in those with a normal bite or an open bite (Table 7). In addition, the mean crown lengths for the mandibular incisors were greater in patients with an open bite than in those with a normal bite or a deep bite. Finally, the R/C ratios for the mandibular incisors were lower in patients with an open bite than in those with a normal bite or a deep bite.

The crown lengths for the maxillary central incisors decreased with increasing age ($r = -0.143$, $p < 0.001$; Table 8). However, the R/C ratios for the maxillary incisors showed no correlation with age. For the mandibular incisors, the crown length decreased (central incisors: $r = -0.162$, $p < 0.001$; lateral incisors: $r = -0.112$, $p < 0.01$) and the R/C ratios increased ($r = 0.118$–0.136, $p < 0.01$) with increasing age, even though the correlations were very weak.

Table 3. Crown length, root length, and the root–crown ratio for each tooth individually and according to tooth type (n = 672)

Arch	Variable	Right		Left		Central incisors	Lateral incisors
		Lateral	Central	Central	Lateral		
Maxilla	Crown length (mm)	9.7 ± 0.8 (7.1–12.8)	10.8 ± 0.9 (8.6–14.2)	10.9 ± 0.8 (8.5–13.6)	9.7 ± 0.8 (7.0–13.3)	10.9 ± 0.8 (8.6–13.8)	9.7 ± 0.8 (7.2–13.1)
	Root length (mm)	11.9 ± 1.3 (7.6–16.7)	11.9 ± 1.6 (6.5–16.7)	11.9 ± 1.5 (6.1–16.2)	11.9 ± 1.4 (6.2–16.3)	11.9 ± 1.5 (6.7–16.5)	11.9 ± 1.2 (6.9–16.4)
	Root-crown ratio	1.2 ± 0.1 (0.7–1.7)	1.1 ± 0.3 (0.6–1.7)	1.1 ± 0.2 (0.5–1.6)	1.2 ± 0.2 (0.6–1.9)	1.1 ± 0.2 (0.6–1.7)	1.2 ± 0.1 (0.7–1.8)
Mandible	Crown length (mm)	8.8 ± 0.7 (6.2–10.8)	8.6 ± 0.7 (6.4–10.8)	8.5 ± 0.7 (6.0–11.0)	8.7 ± 0.7 (6.4–11.1)	8.6 ± 0.7 (6.3–10.5)	8.8 ± 0.7 (6.6–10.8)
	Root length (mm)	12.2 ± 1.1 (8.3–15.8)	11.1 ± 1.1 (6.5–16.4)	11.0 ± 1.1 (6.4–14.7)	12.1 ± 1.1 (7.5–15.6)	11.0 ± 1.0 (6.5–15.3)	12.1 ± 1.0 (7.9–15.6)
	Root-crown ratio	1.4 ± 0.1 (0.9–1.9)	1.3 ± 0.1 (0.7–2.0)	1.3 ± 0.2 (0.7–1.8)	1.4 ± 0.1 (0.8–2.1)	1.3 ± 0.1 (0.7–1.9)	1.4 ± 0.1 (0.9–1.9)

Values are presented as mean ± standard deviation (range).

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Table 4. Crown length, root length, and the root–crown ratio according to sex (n = 672)

Arch	Variable	Right		Left		Central incisors	Lateral incisors
		Lateral	Central	Central	Lateral		
Maxilla	Crown length (mm)						
	Men	10.1 ± 0.7	11.4 ± 0.8	11.4 ± 0.8	10.1 ± 0.9	11.4 ± 0.8	10.1 ± 0.8
	Women	9.6 ± 0.8	10.7 ± 0.9	10.8 ± 0.8	9.6 ± 0.8	10.8 ± 0.8	9.6 ± 0.7
	p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Root length (mm)						
	Men	12.4 ± 1.3	12.5 ± 1.6	12.4 ± 1.6	12.5 ± 1.3	12.4 ± 1.5	12.4 ± 1.2
	Women	11.8 ± 1.2	11.7 ± 1.5	11.7 ± 1.4	11.8 ± 1.4	11.7 ± 1.4	11.8 ± 1.2
	p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Root-crown ratio						
	Men	1.2 ± 0.1	1.1 ± 0.2	1.1 ± 0.2	1.2 ± 0.2	1.1 ± 0.2	1.2 ± 0.1
	Women	1.2 ± 0.1	1.1 ± 0.3	1.1 ± 0.2	1.2 ± 0.2	1.1 ± 0.2	1.2 ± 0.1
	p-value	0.536	0.755	0.940	0.985	0.899	0.792
Mandible	Crown length (mm)						
	Men	9.1 ± 0.7	8.9 ± 0.7	8.8 ± 0.7	9.1 ± 0.7	8.8 ± 0.7	9.1 ± 0.7
	Women	8.7 ± 0.7	8.5 ± 0.7	8.5 ± 0.7	8.6 ± 0.7	8.5 ± 0.6	8.7 ± 0.6
	p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Root length (mm)						
	Men	12.7 ± 1.2	11.7 ± 1.1	11.6 ± 1.1	12.7 ± 1.1	11.6 ± 1.0	12.7 ± 1.1
	Women	12.0 ± 1.0	10.9 ± 1.0	10.8 ± 1.0	12.0 ± 1.0	10.9 ± 1.0	12.0 ± 0.9
	p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Root-crown ratio						
	Men	1.4 ± 0.2	1.3 ± 0.2	1.3 ± 0.1	1.4 ± 0.2	1.3 ± 0.1	1.4 ± 0.1
	Women	1.4 ± 0.1	1.2 ± 0.1	1.2 ± 0.2	1.4 ± 0.1	1.2 ± 0.1	1.4 ± 0.1
	p-value	0.244	0.005	0.002	0.496	0.001	0.280

Values are presented as mean ± standard deviation.
p-values were calculated using the Mann-Whitney *U*-test.

DISCUSSION

Baseline radiographs can be used as a reference and compared with radiographs obtained after treatment to predict the prognosis of the target tooth in patients with orthodontic disorders. Previous studies have shown that patients with existing root resorption at the start of treatment exhibit a greater possibility of severe root resorption during treatment than do patients without existing root resorption.[6,15,16] However, previous studies have shown that the use of radiography for tooth measurements has several limitations.[10-12] Therefore, this study aimed to use CBCT to establish reference data for normal crown and root lengths and the R/C ratios for the maxillary and mandibular incisors with complete root formation in a Korean population. The specific aim of the study was to evaluate the correlations of the CBCT measurements with demographic factors (sex and age) and sagittal and vertical skeletal or occlusal relationships.

The R/C ratio may be classified as either anatomical or clinical. While the clinical R/C ratio is obtained using a reference line drawn from the labial to the palatal crestal bone level, the anatomical R/C ratio is obtained using the CEJ as a reference point.[9] Most previous studies using panoramic radiographs have determined the clinical R/C ratio, because the CEJ could not be precisely determined on these radiographs.[9,17] Because precise identification of the CEJ is essential for studies on root resorption during orthodontic treatment, previous studies using periapical radiographs have used this landmark as a reference to measure the amount of external apical root resorption.[18-20] However, Brezniak et al.[12] reported that angular differences between the

Table 5. Crown length, root length, and the root–crown ratio according to skeletal classification (n = 672)

Arch	Variable	Right		Left		Central incisors	Lateral incisors
		Lateral	Central	Central	Lateral		
Maxilla	Crown length (mm)						
	Skeletal Class I	9.6 ± 0.8	10.9 ± 0.9	11.0 ± 0.8	9.6 ± 0.9	10.9 ± 0.8	9.6 ± 0.8
	Skeletal Class II	9.7 ± 0.8	10.8 ± 0.8	10.9 ± 0.8	9.7 ± 0.8	10.9 ± 0.8	9.7 ± 0.7
	Skeletal Class III	9.7 ± 0.8	10.7 ± 1.0	10.8 ± 1.0	9.6 ± 0.9	10.7 ± 1.2	9.7 ± 0.8
	p-value	0.403	0.794	0.675	0.487	0.656	0.289
	Root length (mm)						
	Skeletal Class I	11.7 ± 1.3	11.7 ± 1.6	11.7 ± 1.6	11.7 ± 1.4	11.7 ± 1.5	11.7 ± 1.3
	Skeletal Class II	12.0 ± 1.2	12.1 ± 1.6	12.1 ± 1.4	12.0 ± 1.4	12.1 ± 1.4	12.0 ± 1.2
	Skeletal Class III	11.6 ± 1.4	11.4 ± 1.7	11.3 ± 1.6	11.9 ± 1.3	11.4 ± 1.6	11.7 ± 1.3
	p-value	0.002	0.001	0.003	0.008	0.001	0.002
	Root-crown ratio						
	Skeletal Class I	1.2 ± 0.1	1.1 ± 0.2	1.1 ± 0.2	1.2 ± 0.2	1.1 ± 0.1	1.2 ± 0.1
	Skeletal Class II	1.2 ± 0.1	1.1 ± 0.2	1.1 ± 0.1	1.2 ± 0.2	1.1 ± 0.1	1.2 ± 0.1
	Skeletal Class III	1.2 ± 0.1	1.2 ± 0.2	1.1 ± 0.2	1.2 ± 0.2	1.1 ± 0.2	1.2 ± 0.1
	p-value	0.047	0.003	0.005	0.079	0.001	0.038
Mandible	Crown length (mm)						
	Skeletal Class I	8.8 ± 0.7	8.6 ± 0.7	8.5 ± 0.7	8.7 ± 0.7	8.7 ± 0.7	8.7 ± 0.7
	Skeletal Class II	8.8 ± 0.7	8.6 ± 0.7	8.5 ± 0.7	8.7 ± 0.7	8.5 ± 0.6	8.7 ± 0.7
	Skeletal Class III	8.9 ± 0.5	8.6 ± 0.8	8.7 ± 0.7	9.0 ± 0.8	8.6 ± 0.7	9.0 ± 0.6
	p-value	0.697	0.644	0.970	0.941	0.754	0.849
	Root length (mm)						
	Skeletal Class I	12.0 ± 1.0	11.0 ± 1.1	10.9 ± 1.2	12.1 ± 1.1	10.9 ± 1.1	12.0 ± 1.0
	Skeletal Class II	12.3 ± 1.1	11.2 ± 1.1	11.1 ± 1.0	12.2 ± 1.1	11.1 ± 1.0	12.2 ± 1.0
	Skeletal Class III	12.1 ± 1.2	10.7 ± 1.2	10.7 ± 1.1	12.0 ± 0.9	10.7 ± 1.1	12.0 ± 1.0
	p-value	0.003	0.025	0.007	0.085	0.014	0.015
	Root-crown ratio						
	Skeletal Class I	1.4 ± 0.1	1.3 ± 0.1	1.3 ± 0.2	1.4 ± 0.2	1.3 ± 0.1	1.4 ± 0.1
	Skeletal Class II	1.4 ± 0.1	1.3 ± 0.1	1.3 ± 0.1	1.4 ± 0.1	1.3 ± 0.1	1.4 ± 0.1
	Skeletal Class III	1.4 ± 0.1	1.2 ± 0.2	1.2 ± 0.2	1.3 ± 0.1	1.2 ± 0.1	1.3 ± 0.1
	p-value	0.012	0.056	0.051	0.082	0.036	0.023

Values are presented as mean ± standard deviation.
p-values were calculated using the Kruskal-Wallis test.

tooth and the film have statistically significant effects on the identification of the labial and palatal CEJ points on periapical radiographs. Therefore, in the present study, the anatomical R/C ratios for the incisors were measured using CBCT, which provides distortion-free slice images of single roots that facilitate the investigation of anterior tooth crown and root lengths and the R/C ratios.[10]

In the present study, the R/C ratios for the maxillary and mandibular incisors ranged from 1.1 to 1.4 (Table 2). The lowest anatomical R/C ratios were determined for the maxillary central incisors (1.1 ± 0.2). Hölttä et al.,[7] who used panoramic radiographs in their study of a Finnish population, reported that the R/C ratios for the maxillary central incisors were 1.86 ± 0.17 in men and 1.78 ± 0.16 in women. Yun et al.[9] also used panoramic graphs in their study of a Korean population and found that the R/C ratios for the maxillary central incisors were 1.49 ± 0.20 in both men and women. In the field of restorative dentistry, 1.5 is considered a clinically acceptable R/C ratio for an abutment for a fixed prosthesis, whereas

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Table 6. Crown length, root length, and the root–crown ratio according to overjet (OJ) (n = 672)

Arch	Variable	Right		Left		Central incisors	Lateral incisors
		Lateral	Central	Central	Lateral		
Maxilla	Crown length (mm)						
	Normal OJ	9.6 ± 0.8	10.8 ± 1.0	10.9 ± 0.8	9.6 ± 0.8	10.8 ± 0.8	9.6 ± 0.8
	Excessive OJ	9.8 ± 0.8	10.9 ± 0.8	11.0 ± 0.8	9.7 ± 0.8	11.0 ± 0.8	9.7 ± 0.8
	Cross bite	9.7 ± 0.6	10.6 ± 1.1	10.7 ± 1.1	9.5 ± 1.0	10.7 ± 1.1	9.6 ± 0.8
	p-value	0.309	0.203	0.512	0.855	0.345	0.571
	Root length (mm)						
	Normal OJ	11.9 ± 1.3	11.8 ± 1.6	11.7 ± 1.5	11.8 ± 1.4	11.8 ± 1.5	11.8 ± 1.3
	Excessive OJ	12.0 ± 1.3	12.1 ± 1.5	12.1 ± 1.4	12.1 ± 1.3	12.1 ± 1.4	12.0 ± 1.2
	Cross bite	11.8 ± 1.2	11.6 ± 1.9	11.4 ± 1.5	11.9 ± 1.1	11.5 ± 1.6	11.8 ± 1.1
	p-value	0.260	0.038	0.010	0.118	0.013	0.137
	Root-crown ratio						
	Normal OJ	1.2 ± 0.1	1.1 ± 0.4	1.1 ± 0.2	1.2 ± 0.2	1.1 ± 0.2	1.2 ± 0.1
	Excessive OJ	1.2 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.2 ± 0.1	1.1 ± 0.1	1.2 ± 0.1
	Cross bite	1.2 ± 0.1	1.1 ± 0.2	1.1 ± 0.2	1.3 ± 0.2	1.1 ± 0.2	1.2 ± 0.1
	p-value	0.818	0.446	0.071	0.231	0.180	0.547
Mandible	Crown length (mm)						
	Normal OJ	8.8 ± 0.7	8.6 ± 0.7	8.5 ± 0.7	8.8 ± 0.7	8.5 ± 0.7	8.8 ± 0.7
	Excessive OJ	8.7 ± 0.7	8.6 ± 0.7	8.5 ± 0.7	8.7 ± 0.7	8.6 ± 0.7	8.7 ± 0.7
	Cross bite	9.0 ± 0.6	8.6 ± 0.8	8.8 ± 0.7	8.9 ± 1.0	8.7 ± 0.7	9.0 ± 0.7
	p-value	0.088	0.894	0.257	0.274	0.652	0.145
	Root length (mm)						
	Normal OJ	12.1 ± 1.1	11.0 ± 1.1	10.9 ± 1.1	12.1 ± 1.1	10.9 ± 1.0	12.1 ± 1.0
	Excessive OJ	12.3 ± 1.1	11.2 ± 1.1	11.2 ± 1.1	12.2 ± 1.1	11.2 ± 1.0	12.3 ± 1.0
	Cross bite	12.0 ± 1.1	10.7 ± 1.1	10.9 ± 1.2	12.0 ± 1.0	10.8 ± 1.1	12.0 ± 1.0
	p-value	0.020	0.014	0.006	0.223	0.006	0.053
	Root-crown ratio						
	Normal OJ	1.4 ± 0.1	1.3 ± 0.1	1.3 ± 0.2	1.4 ± 0.2	1.3 ± 0.1	1.4 ± 0.1
	Excessive OJ	1.4 ± 0.1	1.3 ± 0.1	1.3 ± 0.1	1.4 ± 0.1	1.3 ± 0.1	1.4 ± 0.1
	Cross bite	1.3 ± 0.1	1.3 ± 0.1	1.2 ± 0.2	1.4 ± 0.2	1.2 ± 0.1	1.3 ± 0.1
	p-value	< 0.001	0.053	0.005	0.017	0.006	0.001

Values are presented as mean ± standard deviation.
p-values were calculated using the Kruskal–Wallis test.

1:1 is the minimum ratio for abutments under normal circumstances.[8] However, the R/C ratios for all the maxillary central incisors in the present study and the study by Yun et al.[9] were lower than 1.5. These results indicate that the roots are relatively longer in Caucasian teeth than in Korean teeth. Therefore, ethnicity-related differences in measurements should be considered when establishing appropriate orthodontic reference values.

Table 3 shows that crown and root lengths were greater in men than in women. In the present study, root lengths for the maxillary central incisors were 12.4 ± 1.5 mm and 11.7 ± 1.4 mm in men and women, respectively. Kim et al.[14] also reported values of 12.3 ± 1.6 mm and 11.8 ± 1.5 mm for the maxillary central incisors in men and women, respectively, by using CBCT. These results are consistent with those of most previous studies, which reported that the maxillary and mandibular incisors in men are approximately 0.5 to 1.0 mm longer than those in women, even though the R/C ratios between men and women showed no significant

Table 7. Crown length, root length, and the root–crown ratio according to overbite (OB) (n = 672)

Arch	Variable	Right		Left		Central incisors	Lateral incisors
		Lateral	Central	Central	Lateral		
Maxilla	Crown length (mm)						
	Normal OB	9.6 ± 0.8	10.8 ± 0.8	10.9 ± 0.8	9.6 ± 0.8	10.8 ± 0.8	9.6 ± 0.8
	Deep bite	9.9 ± 0.8	11.1 ± 1.2	11.2 ± 0.8	9.8 ± 0.9	11.1 ± 0.9	9.8 ± 0.8
	Open bite	9.7 ± 0.7	10.8 ± 0.9	10.8 ± 0.9	9.8 ± 0.9	10.8 ± 0.9	9.7 ± 0.7
	p-value	0.006	0.001	< 0.001	0.362	< 0.001	0.054
	Root length (mm)						
	Normal OB	11.9 ± 1.2	11.8 ± 1.6	11.8 ± 1.5	11.9 ± 1.4	11.8 ± 1.5	11.9 ± 1.2
	Deep bite	12.2 ± 1.3	12.1 ± 1.6	12.0 ± 1.5	12.1 ± 1.4	12.1 ± 1.5	12.1 ± 1.3
	Open bite	11.6 ± 1.3	11.8 ± 1.6	11.9 ± 1.4	11.5 ± 1.3	11.8 ± 1.4	11.6 ± 1.2
	p-value	0.002	0.110	0.185	0.033	0.106	0.004
	Root-crown ratio						
	Normal OB	1.2 ± 0.1	1.1 ± 0.2	1.1 ± 0.2	1.2 ± 0.2	1.1 ± 0.1	1.2 ± 0.1
	Deep bite	1.2 ± 0.1	1.1 ± 0.6	1.1 ± 0.1	1.2 ± 0.2	1.1 ± 0.2	1.2 ± 0.1
	Open bite	1.2 ± 0.1	1.1 ± 0.2	1.1 ± 0.1	1.2 ± 0.1	1.1 ± 0.3	1.2 ± 0.1
	p-value	0.289	0.939	0.443	0.057	0.915	0.071
Mandible	Crown length (mm)						
	Normal OB	8.8 ± 0.7	8.6 ± 0.7	8.5 ± 0.7	8.7 ± 0.7	8.5 ± 0.7	8.7 ± 0.7
	Deep bite	8.8 ± 0.6	8.6 ± 0.7	8.6 ± 0.7	8.8 ± 0.7	8.6 ± 0.7	8.8 ± 0.6
	Open bite	9.0 ± 0.7	8.8 ± 0.7	8.9 ± 0.7	9.0 ± 0.7	8.9 ± 0.7	9.0 ± 0.6
	p-value	0.107	0.115	0.006	0.047	0.019	0.043
	Root length (mm)						
	Normal OB	12.1 ± 1.1	11.0 ± 1.1	10.9 ± 1.0	12.1 ± 1.1	11.0 ± 1.0	12.1 ± 1.0
	Deep bite	12.5 ± 1.2	11.3 ± 1.2	11.3 ± 1.2	12.4 ± 1.1	11.3 ± 1.1	12.4 ± 1.1
	Open bite	11.9 ± 1.1	11.0 ± 1.0	10.9 ± 1.0	11.8 ± 1.0	10.9 ± 1.0	11.9 ± 1.0
	p-value	0.001	0.002	0.001	0.001	< 0.001	< 0.001
	Root-crown ratio						
	Normal OB	1.4 ± 0.1	1.3 ± 0.1	1.3 ± 0.2	1.4 ± 0.1	1.3 ± 0.1	1.4 ± 0.1
	Deep bite	1.4 ± 0.2	1.3 ± 0.2	1.3 ± 0.2	1.4 ± 0.2	1.3 ± 0.1	1.4 ± 0.1
	Open bite	1.3 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.3 ± 0.1	1.2 ± 0.1	1.3 ± 0.1
	p-value	0.002	0.003	0.003	< 0.001	0.001	< 0.001

Values are presented as mean ± standard deviation.
p-values were calculated using the Kruskal-Wallis test.

differences.[14,21]

In the present study, patients with skeletal Class II malocclusion or an excessive overjet showed greater incisor root lengths in both arches and greater R/C ratios for the mandibular incisors than did patients with other sagittal relationships. This finding is clinically interesting because several studies have reported that premolar extraction for Class II camouflage treatment and an excessive overjet may be considered risk factors for external apical root resorption after orthodontic treatment.[4,22-24] Sameshima and Sinclair[4,5] reported that extraction treatment for the correction of an excessive overjet and a skeletal Class II malocclusion can cause severe root resorption in the anterior teeth of adult patients because of a longer treatment duration.

In addition, the present study showed that patients with an open bite exhibited significantly lower R/C ratios for the mandibular incisors than did patients with a normal bite or a deep bite. Uehara et al.[25] reported that patients with an open bite exhibit an unfavorable R/C

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Table 8. Correlations between crown length, root length, the root–crown ratio, and age (n = 672)

Variable		Dimension	Right		Left		Central incisors	Lateral incisors
			Lateral	Central	Central	Lateral		
Age	Maxilla	Crown length (mm)						
		r	–0.092	–0.146	–0.131	–0.059	–0.143	–0.078
		p-value	0.018	< 0.001	0.001	0.125	< 0.001	0.043
		Root length (mm)						
		r	–0.070	–0.043	–0.038	–0.031	–0.045	–0.052
		p-value	0.068	0.269	0.320	0.416	0.245	0.177
		Root-crown ratio						
		r	0.011	0.039	0.033	0.013	0.033	0.014
		p-value	0.774	0.310	0.392	0.740	0.396	0.727
	Mandible	Crown length (mm)						
		r	–0.092	–0.150	–0.157	–0.113	–0.162	–0.112
		p-value	0.017	< 0.001	< 0.001	0.003	< 0.001	0.004
		Root length (mm)						
		r	0.000	–0.012	0.001	0.026	–0.007	0.013
		p-value	0.995	0.749	0.978	0.504	0.847	0.742
		Root-crown ratio						
		r	0.076	0.111	0.128	0.137	0.136	0.118
		p-value	0.049	0.004	0.001	< 0.001	0.001	0.002

ratio and short roots, which may be associated with the loss of occlusal contacts. Occlusal hypofunction due to an open bite may decrease the possibility of incisal edge attrition and lead to atrophic changes in the periodontal ligament and root resorption. In contrast, patients with a deep bite exhibited significantly higher R/C ratios for the mandibular incisors than did patients with a normal bite or an open bite. Several previous studies agree that a deep bite is not associated with severe root resorption.[6,26] However, the intrusion force required for deep bite correction and the amount of correction can be correlated with root resorption during treatment.[27,28]

The crown lengths for the maxillary and mandibular central incisors decreased with an increase in the age of the patients in the present study; however, these correlations were very weak (Table 4). Because patients with severe attrition and those treated with occlusal adjustments were excluded from our study, this correlation could be attributed to physiological incisal attrition associated with aging. For the mandibular incisors in particular, the crown length decreased and the R/C ratios significantly increased with increasing age.

This study has several limitations that should be considered during data interpretation. First, the sex ratio was skewed; there were more women (79.0%) than men (21.0%). Although there were no significant differences in the R/C ratios for most teeth between men and women, the skewed sex distribution may have resulted in relatively lower R/C ratios in the present study than in previous studies on Korean populations.[9,14] Second, although our CBCT data were validated by previous studies, the values could have been significantly lower than those obtained by direct measurements of extracted teeth, depending on the Hounsfield unit (HU) range.[14] Kim et al.[14] reported that CBCT measurements of root lengths may have been significantly shorter than direct measurements under a higher HU range. Lund et al.[10] reported that the in vitro mean difference between anatomical and CBCT measurements was 0.05 ± 0.75 mm for the root length. Because the voxel size used in the present study (0.2–0.3 mm) was greater than that used in the study by Lund et al.9 (0.125 mm), the difference between anatomical and CBCT measurements may have been greater than 0.05 mm in the present study. Future studies using CBCT-based measurements with improved accuracy and precision are necessary to clarify our findings.

CONCLUSION

Although the assessment of R/C ratios using CBCT data has inherent limitations with regard to accuracy, we obtained the mean R/C ratios for the maxillary and mandibular incisors in a Korean population. The mean

R/C ratios varied from 1.1 to 1.2 for the maxillary incisors and from 1.3 to 1.4 for the mandibular incisors. R/C ratios for the mandibular central incisors were greater in men than in women. Root lengths and R/C ratios for the mandibular incisors were significantly greater in patients with skeletal Class II malocclusion or an excessive overjet than in patients with other sagittal relationships. However, root lengths and R/C ratios were lower in patients with an open bite than in patients with a normal overbite. Finally, crown lengths for the maxillary central incisors and all mandibular incisors decreased with increasing age, whereas R/C ratios for the mandibular incisors increased with increasing age. We believe that the data obtained in the present study can serve as a reference for maxillary and mandibular incisor crown and root lengths and R/C ratios in the Korean population.

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