Original Article

Relationships between the root-crown ratio and the loss of occlusal contact and high mandibular plane angle in patients with open bite

Sawako Uehara[a]; Aya Maeda[b]; Hiroshi Tomonari[b]; Shouichi Miyawaki[c]

ABSTRACT

Objective: To determine the root-crown (R/C) ratio and dental root length of teeth in patients with open bite and seek any relationships with occlusal contact (OC) and the mandibular plane (Mp) angle.

Materials and Methods: Thirty-one patients with open bite with negative overbite of at least four anterior teeth and 31 control patients with clinically normal overjet and overbite were enrolled. R/C ratios, dental root length, OC, and Mp angle were measured using panoramic radiographs, dental casts, and cephalograms, respectively. Mean differences between the groups, and variations between the R/C ratio or root length and Mp angle in patients with open bite were statistically analyzed.

Results: R/C and OC ratios from the incisors to premolars were significantly lower for patients with open bite than for controls, and some teeth had short dental roots. Relationships between low R/C ratio or root length and high Mp angle were significant in patients with open bite.

Conclusion: Patients with open bite, especially those with a high Mp angle, have an unfavorable R/C ratio and short dental roots in some teeth, which may be related to the loss of OC. (*Angle Orthod.* 2013;83:36–42.)

KEY WORDS: Open bite; Root-crown ratio; Root length; Occlusal contact; High mandibular-plane angle

INTRODUCTION

According to a recent epidemiologic study, elderly people with many teeth have relatively good occlusion; their incidence of open-bite malocclusion is very low.[1] This suggests that loss of occlusal contact (OC), as in open-bite malocclusion, may increase the loss of teeth. Studies of root morphology have shown that patients with open bite are at risk for root resorption during orthodontic treatment.[2,3] The dental roots of maxillary central incisors in patients with open bite have been reported to be short.[4] Moreover, the loss of normal occlusal function or OC, that is, occlusal hypofunction due to tooth loss or in malocclusions such as open bite, leads to root resorption during tooth movement.[5] Thus, open-bite malocclusion and loss of OC play an important role in dental root morphology, although the details remain unclear. Additionally, open bite has various morphologic features, such as high mandibular plane (Mp) angle and long face.[6] It has been reported that patients with open bite and/or long face often exhibit a weak occlusal force.[6] In addition, low occlusal stimuli may cause malocclusion and morphologic features such as open bite and long face.[7] However, the relationship between the dental root length and the Mp angle is unclear. In this study, we focused on the dental root length, OC, and high Mp angle in patients with open bite.

An unfavorable root-crown (R/C) ratio due to short dental roots may affect the prognosis of teeth. Clinically, a short root may complicate treatment

[a] Postgraduate Student, Department of Orthodontics, Field of Developmental Medicine, Health Research Course, Graduate School of Medical and Dental Sciences, Kagoshima University, Kagoshima, Japan.
[b] Assistant Professor, Department of Orthodontics, Field of Developmental Medicine, Health Research Course, Graduate School of Medical and Dental Sciences, Kagoshima University, Kagoshima, Japan.
[c] Professor and Department Chair, Department of Orthodontics, Field of Developmental Medicine, Health Research Course, Graduate School of Medical and Dental Sciences, Kagoshima University, Kagoshima, Japan.
Corresponding author: Dr Shouichi Miyawaki, Department of Orthodontics, Field of Developmental Medicine, Health Research Course, Graduate School of Medical and Dental Sciences, Kagoshima University, 8-35-1 Sakuragaoka, Kagoshima 890-8544, Japan
(e-mail: miyawaki@dent.kagoshima-u.ac.jp)

Accepted: July 2012. Submitted: April 2012.
Published Online: August 16, 2012

 DOI: 10.2319/042412-341.1

Table 1. Summary of Subject Data[a]

	Control Group	Open-Bite Group	*P* Value
Number	31	31	
Age (y; mean ± SD)	24.2 ± 4.0	22.5 ± 5.9	NS[b]
Gender (female/total)	21/31	17/31	NS[c]

[a] NS indicates not significant.
[b] Unpaired *t*-test.
[c] Fisher's exact test.

planning in orthodontic management or prosthodontics, because short roots influence the anchorage and mobility of teeth. Short dental roots have been observed in some disorders, including Down syndrome,[8] Turner syndrome,[9] and cleft lip and palate.[10] Some studies have reported that teeth with open-bite malocclusion are at high risk for root resorption during orthodontic treatment.[2,3] However, few studies have evaluated the original dental root length in patients with open bite.[4] The purpose of this study was to examine the R/C ratio and dental root length of all teeth in patients with open bite and its relationships to OC and the Mp angle.

MATERIALS AND METHODS

Subjects

From 1998 to 2011, 1473 patients visited the Department of Orthodontics at Kagoshima University Medical and Dental Hospital, Kagoshima, Japan, and were diagnosed using panoramic and cephalometric radiographs and dental casts. Among these 1473 consecutive patients, all patients who met the following exclusion and inclusion criteria were selected as open-bite or control group subjects in the present study. Exclusion criteria for both groups were (1) <15 years old, because the third molars and other permanent tooth roots complete their growth around 14 years; (2) cleft lip and/or palate; (3) craniofacial syndromes; (4) loss of >1 permanent tooth; or (5) history of orthodontic treatment. Inclusion criterion for the open-bite group was a negative overbite of at least 4 anterior teeth, and inclusion criteria for the control group were a 1–4 mm overbite and a 1–4 mm overjet. Ultimately, the open-bite group consisted of 31 patients with open bite, and the control group consisted of 31 patients with malocclusion. No significant differences were noted in the mean age or the female to male ratio between the open-bite and control groups (Table 1). The study design was approved by the Kagoshima University Ethics Committee (#183).

Measurements

Cephalometrics. We used lateral cephalometric radiographs, taken for orthodontic diagnosis for all subjects, to reveal the characteristics of dentofacial morphologies. The radiographs were traced by the authors, and landmarks were identified and digitized with a protractor and digital caliper. Bilateral structures were bisected and their midsagittal points were identified. To assess intraexaminer reproducibility and reliability of the measurements, 15 cephalometric radiographs were retraced at a minimum interval of 2 months. Differences between the original and retraced radiographs were statistically analyzed using a matched paired *t*-test. The cephalometric analysis indicated no statistically significant differences between the original and repeat measurements.

Dental casts. Dental wear was assessed using the tooth wear index[11] because individual teeth with substantial tooth wear were excluded in this study. Moreover, the percentage of patients with OC on each tooth in the centric occlusion position was examined by dental cast. If contact was detected at least one point for each tooth, the patient was considered to have OC.

Panoramic radiographs. We used R/C ratios in dental panoramic radiographs showing the maxilla and mandible to assess the dental root length using the method of Lind.[12–15] Outlines of the permanent maxillary and mandibular teeth were traced on acetate sheets from the panoramic radiographs, and the root apex point, incisal edge point, and cement enamel junction point were additionally marked. In teeth with two roots, the root apex point was chosen as the buccal root; in teeth with two buccal roots, the longer root was marked as the root apex point. In most incisors and molars, two points on the mesial and distal incisal edges or buccal cusps were marked as the incisal edge points. In canines and most premolars, one point was marked as the incisal edge point. The acetate sheets with the outlines of the teeth and critical points were scanned at 1000 dpi resolution and viewed on a large monitor, and each point on the scanned images was retraced. For measuring the R/C ratio, three parallel reference lines were drawn on the basis of points traced on the large monitor. Crown height was measured along the perpendicular line from line *i* to line *m*. Root length was measured along the perpendicular line from line *a* to line *m* (Figure 1). The R/C ratio of an individual tooth was calculated by dividing the root length by the crown height. The criteria for excluding individual teeth were as follows: (1) the reference points were not clearly visible, that is, there was major overlapping of teeth (n = 23), diffuse images (n = 9), outside the image layer (n = 10), or overlapping of the cervical spine (n = 4); (2) extensive caries, restorations, or endodontic treatment (n = 114); or (3) a tooth wear index score >1 (n = 50).

To support the low accuracy of the dental panoramic radiographs, we evaluated the method error (ME) for use of dental panoramic radiographs compared with

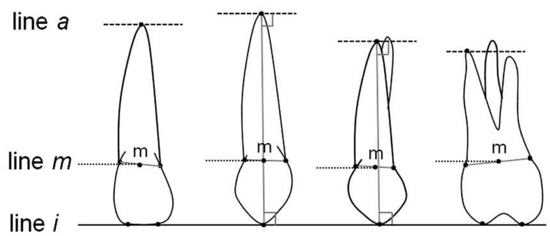

Figure 1. Measurement of the root-crown (R/C) ratio in a tooth. Line *i*, connecting the incisal edges or buccal cusps; line *a*, touching the outermost part of the root and forming a tangent to the root apex point; and line *m*, through the midpoint (*m*) of the line between the mesial and distal sides of the cement enamel junction. Crown height was measured along the perpendicular line from line *i* to line *m*. Root length was measured along the perpendicular line from line *a* to line *m*. The R/C ratio was calculated by dividing the root length by the crown height.

periapical radiographs of the maxillary and mandibular central incisors of 23 subjects who had both types of radiographs taken during the same period. These teeth were chosen because the measurement reliability for incisors on panoramic radiographs is the lowest among all tooth types.[16] The MEs for the R/C ratios and dental root length were calculated using Dahlberg's formula[17]:

$$\mathrm{ME} = \sqrt{\sum (d^2/2n)}$$

where d is the difference in the R/C ratio or root length between the panoramic radiographs and periapical radiographs and *n* is the number of teeth for which the measurement was conducted. The MEs for the R/C ratio and root length are shown in Table 2. When the mean difference for the R/C ratio or root length between the control and open-bite groups was less than the ME, we considered it not significant.

To assess intraexaminer reproducibility and reliability of the measurements, 332 teeth on 12 panoramic radiographs were retraced at a minimum interval of 2 months. Panoramic radiographs in which fewer than two individual teeth were excluded were chosen for the reproducibility study. The precision of the R/C ratio and root length measurements were calculated as the ME. Differences between the original and retraced radiographs were statistically analyzed using a paired *t*-test. The correlations for the repeated intraexaminer R/C ratio and root length assessment analysis showed no statistically significant differences. The mean ME values for the R/C ratio and root length were 0.088 (range, 0.064–0.110) and 0.50 mm (range, 0.29–0.89), respectively.

Statistical Analysis

Differences in all variables between the open-bite and control groups were analyzed. With respect to numeric variables (age, cephalometric analysis, R/C ratio, root length), significance was determined using an unpaired *t*-test for normally distributed variables or a Mann-Whitney *U* test for non-normally distributed variables. For categoric variables (gender, percent OC), significance was determined using Fisher's exact test. The observed probability was calculated for each comparison, and $P < .05$ was considered statistically significant.

Random intercept models were used to evaluate the differences in the R/C ratio and dental root length with Mp angle for the open-bite group. Multilevel linear modeling[18,19] was used in this study to reflect varying data hierarchies. The data at the highest-level hierarchy (level 2) were the Mp angle in the subjects. The data at the next level down (level 1) were the R/C ratio and root length for each of the 14 tooth types. The variance components model was used to evaluate the need to consider clustered hierarchical data at the tooth level (between tooth types). Among multilevel linear statistical models, the variance components model was the simplest hierarchical model containing no explanatory variables and was used to establish a mean outcome value.

Statistical tests were performed using conventional statistical analysis software (SPSS for Windows, SPSS Japan, Tokyo, Japan).

RESULTS

In the analysis of maxillofacial morphology by cephalometric radiography, in the patients with open

Table 2. ME, Mean, and SD for the R/C Ratio and Root Length of the Maxillary Central Incisor and Mandibular Central Incisor Measured Using Periapical and Dental Panoramic Radiographs[a]

	Control Group				Open-Bite Group			
			Periapical X-p	Panoramic X-p			Periapical X-p	Panoramic X-p
Measurements	ME	n	Mean ± SD	Mean ± SD	ME	n	Mean ± SD	Mean ± SD
R/C ratio of U1	0.18	23	1.76 ± 0.14	1.91 ± 0.18	0.16	19	1.46 ± 0.17	1.63 ± 0.13
R/C ratio of L1	0.13	23	1.99 ± 0.09	2.09 ± 0.18	0.14	16	1.78 ± 0.18	1.75 ± 0.23
Root length of U1	1.56	23	16.4 ± 0.1	18.2 ± 1.4	1.35	19	14.7 ± 1.7	16.4 ± 2.1
Root length of L1	0.95	23	14.6 ± 0.5	14.4 ± 1.4	1.30	16	13.6 ± 1.7	12.2 ± 1.6

[a] n indicates number of teeth; U1, maxillary central incisor; L1, mandibular central incisor.

Table 3. Cephalometric Measurements for the Control and Open-Bite Groups[a]

Measurements	Control Group (n = 31)	Open-Bite Group (n = 31)	
	Mean ± SD	Mean ± SD	*P* Value[b]
Angular (°)			
SNA	81.9 ± 3.2	81.7 ± 4.9	NS
SNB	78.7 ± 3.4	80.1 ± 5.0	NS
Mp-SN	34.8 ± 6.4	42.9 ± 6.6	***
U1-FH	114.3 ± 6.7	118.0 ± 7.6	NS
L1-FH	56.4 ± 10.0	57.1 ± 12.0	NS
Linear (mm)			
Overjet	3.0 ± 0.7	1.8 ± 3.7	NS
Overbite	2.7 ± 1.0	−3.7 ± 2.8	***

[a] NS indicates not significant; SNA angle, angle between the lines N-A and S-N; SNB angle, angle between N-B and S-N; Mp-SN angle, angle between the mandibular plane and S-N; U1-FH, angle between the maxillary incisor axis and FH; L1-FH, angle between the mandibular incisor axis and FH.

[b] Mann-Whitney *U*-test.

*** $P < .001$.

bite, the angles between the mandibular plane and S-N (Mp-SN angle) were significantly larger than those of the control group, whereas the overbites of the patients with open bite were smaller than those of the control group (Table 3). In the analysis of dental casts, the percent OC in the open-bite group, other than for molars, was significantly lower than that in the control group (Table 4).

R/C ratios were calculated for 1515 teeth. R/C ratios in the open-bite group were significantly lower than those in the control group for all teeth other than molars (Table 5). In addition, this difference exceeded the ME (0.18 and 0.14 for maxillary and mandibular teeth, respectively). Root lengths in the open-bite group were significantly shorter than those in the control group for all teeth other than the mandibular central incisor and the molars (Table 6). This difference in the maxillary central incisor and premolars exceeded the ME (1.56 and 1.30 for maxillary and mandibular teeth, respectively).

Multilevel linear statistical models were used to evaluate the relationships between the R/C ratio or root length and the Mp-SN angle in the open-bite group. A high Mp-SN angle was defined as having an Mp-SN angle >1 standard deviation (SD) above the mean[20] (number of subjects: open-bite group, 23). The methodology was preliminarily tested using the variance components model at the tooth level (between tooth types). The variance was statistically significant at the tooth level for the Mp-SN angle (Table 7). Therefore, a random effect at the tooth level was incorporated using random intercept models. Among

Table 4. Teeth Showing Occlusal Contact in the Control and Open-Bite Groups[a]

Tooth Type	Control Group	Open-Bite Group	
	% (n/N)	% (n/N)	*P* Value[b]
Maxillary			
Central incisor	90.0 (54/60)	0.0 (0/58)	***
Lateral incisor	89.1 (49/55)	0.0 (0/55)	***
Canine	79.5 (35/44)	13.1 (8/61)	***
First premolar	98.0 (48/49)	53.7 (29/54)	***
Second premolar	97.8 (45/46)	73.1 (38/52)	***
First molar	100.0 (48/48)	90.4 (47/52)	NS
Second molar	100.0 (57/57)	96.3 (52/54)	NS
Mandibular			
Central incisor	91.1 (51/56)	0.0 (0/56)	***
Lateral incisor	93.0 (53/57)	0.0 (0/56)	***
Canine	95.7 (44/46)	8.5 (5/59)	***
First premolar	100.0 (62/62)	36.2 (21/58)	***
Second premolar	98.1 (52/53)	64.2 (34/53)	***
First molar	100.0 (47/47)	91.8 (45/49)	NS
Second molar	100.0 (59/59)	100.0 (59/59)	—

[a] n indicates number of teeth with occlusal contact; N, number of teeth; NS, not significant.

[b] Fisher's exact test.

*** $P < .001$.

Table 5. Difference in R/C Ratio between the Control and Open-Bite Groups[a]

Tooth Type	Control Group Mean ± SD	Open-Bite Group Mean ± SD	MD[b]	*P* Value[c]
Maxillary				
Central incisor	1.93 ± 0.18	1.59 ± 0.15	0.34	***
Lateral incisor	2.06 ± 0.25	1.75 ± 0.23	0.30	***
Canine	2.03 ± 0.17	1.75 ± 0.24	0.27	***
First premolar	2.25 ± 0.27	1.89 ± 0.29	0.36	***
Second premolar	2.23 ± 0.32	1.90 ± 0.30	0.33	***
First molar	1.82 ± 0.22	1.78 ± 0.20	0.04	NS[c]
Second molar	1.82 ± 0.25	1.72 ± 0.20	0.10	NS
Mandibular				
Central incisor	2.04 ± 0.23	1.85 ± 0.25	0.19	***
Lateral incisor	2.02 ± 0.20	1.85 ± 0.23	0.17	***
Canine	2.08 ± 0.20	1.92 ± 0.29	0.16	***
First premolar	2.32 ± 0.26	2.02 ± 0.29	0.30	***
Second premolar	2.43 ± 0.33	2.06 ± 0.37	0.37	***
First molar	2.18 ± 0.19	2.13 ± 0.25	0.06	NS
Second molar	1.99 ± 0.22	1.96 ± 0.29	0.03	NS

[a] NS indicates not significant.
[b] (Mean for R/C in the control group) – (Mean for R/C in the open-bite group).
[c] Mann-Whitney *U*-test.
*** $P < .001$.

the outcome variables for low R/C ratio and root length at the tooth level, a high Mp angle (Mp-SN > 1 SD above the mean) was statistically significant for teeth of the open-bite group (Table 8).

DISCUSSION

It has been reported that R/C ratios and dental root lengths can be measured accurately from panoramic radiographs.[21] We used Lind's method to measure R/C ratios[10,12,14] and dental root lengths[10,14] using panoramic radiographs. In addition, assessing R/C ratios is to be considered more reliable than absolute linear measurements, such as dental root length in a radiographic study, because alterations in tooth angulation are known to affect radiographic tooth length, although the change in R/C ratio is negligible.[15] Therefore, we considered the R/C ratio to be a more reliable measurement than dental root length based on the panoramic radiograph. In addition, we used the ME to

Table 6. Difference in Root Length (mm) between the Control and Open-Bite Groups[a]

Tooth Type	Control Group Mean ± SD	Open-Bite Group Mean ± SD	MD[b]	*P* Value[c]
Maxillary				
Central incisor	18.5 ± 1.6	16.4 ± 2.0	2.10	***
Lateral incisor	18.0 ± 1.7	16.7 ± 2.1	1.39	***
Canine	21.0 ± 2.0	19.7 ± 3.0	1.34	*
First premolar	17.8 ± 1.5	15.7 ± 1.9	2.09	***
Second premolar	16.5 ± 1.9	14.9 ± 2.0	1.57	***
First molar	14.3 ± 1.6	14.1 ± 1.5	0.19	NS
Second molar	13.6 ± 1.6	13.5 ± 1.5	0.08	NS
Mandibular				
Central incisor	13.9 ± 2.1	13.6 ± 1.8	0.38	NS
Lateral incisor	15.1 ± 1.7	14.4 ± 1.6	0.67	*
Canine	19.1 ± 2.4	18.1 ± 4.1	1.03	**
First premolar	17.5 ± 2.0	16.0 ± 1.9	1.55	***
Second premolar	18.2 ± 1.9	16.1 ± 3.0	2.04	***
First molar	16.9 ± 1.4	16.6 ± 1.7	0.30	NS
Second molar	15.8 ± 3.9	15.1 ± 1.7	0.66	NS

[a] NS indicates not significant.
[b] (Mean for root length in the control group) – (Mean for root length in the open-bite group).
[c] Mann-Whitney *U*-test.
* $P < .05$; ** $P < .01$; *** $P < .001$.

Table 7. Variance Components Model for Outcome Variables of the R/C Ratio and Root Length at the Tooth Level (between Tooth Types) in the Open-Bite Group[a]

	No. of Teeth	Estimate (SE)	
		R/C Ratio	Root Length
All teeth examined	776	0.018 (0.007)	2.70 (1.05)
Classification by Mp-SN			
Mp-SN $<$1 SD above the mean	205	0.032 (0.014)	4.14 (1.68)
Mp-SN $>$1 SD above the mean	571	0.016 (0.007)	2.32 (0.92)

[a] All variance estimates significantly differed from zero ($P < .05$), indicating the need to consider clustered hierarchical data at the tooth level.

improve the accuracy of the R/C ratios and dental root lengths. The reproducibility values (ME) for the intraexaminer R/C and root length assessments observed in this study closely coincided with those demonstrated in previous studies.[12,14] Furthermore, we compared the MEs for the R/C ratios and root lengths of dental panoramic radiographs and periapical radiographs. In the present study, when the mean difference for an R/C ratio or root length between the control and open-bite groups was less than the ME, we considered it not significant, thus supporting our use of the dental panoramic radiographs. We believe the statistically significant differences for the R/C ratios between the groups are reliable because these differences were greater than the ME.

The primary causes of short dental roots are disturbances during root development or resorption of the original roots. The background of developmentally short-rooted permanent teeth may be genetic (known as short root anomaly)[8–10] or exogenous, such changes associated with chemotherapy or radiation therapy.[22] In sex-linked genes, several studies have suggested that the promoting effect of the Y chromosome on root growth is greater than that of the X chromosome[14]; this may be the reason for longer roots in males than females. In the present study, patients with malocclusion and craniofacial syndromes were excluded, and the ratio of males to females in the control group was nearly the same as that in the open-bite group. Thus, genetic disorders and sex-linked genes did not influence the results of this study.

Occlusal hypofunction decreases alveolar bone mass and accelerates bone resorption.[23] The loss of normal occlusal function or OC, that is, occlusal hypofunction due to tooth loss or in malocclusions such as open bite, leads to atrophic changes in the periodontal ligament, such as narrowing of the periodontal space, vascular constriction, and deformation of the mechanoreceptor structure.[24,25] In experimental occlusal hypofunction, external root resorption in rat molars during tooth movement was significantly greater than that evinced under normal conditions, because the hypofunctional periodontium exhibited progressive atrophic changes in all functional structures.[26] Therefore, we hypothesized that a decrease in OC would result in shorter roots. In the present study, R/C ratios and OC rates were lower for most of the 14 tooth types in the open-bite group than in the control group. These results suggest that the dental roots from the incisors to premolars in patients with open bite may be short and related to the loss of OC. Therefore, increasing occlusal stimuli by orthodontic treatment of open bite may promote root-length formation in growing patients.

The Mp-SN angle in patients with open bite was significantly larger than in the control patients. Patients with open bite with a high Mp-SN angle often exhibit weak occlusal force.[6] Because dental root lengths change due to occlusal hypofunction,[26] we hypothesized that a high Mp-SN angle would result in shorter roots. In the open-bite group, we evaluated the relationships between the R/C ratios and the Mp-SN angle. However, the R/C ratios and Mp-SN angle were within different levels of the data hierarchy. In addition, sample sizes for each of the 14 tooth types classified by the Mp-SN angle were unequal. This problem was overcome by the use of multilevel linear models[18,19] at the tooth level. We found that a high Mp-SN angle was related to a low R/C ratio and dental root length in patients with open bite. These results suggest that patients with open bite with a high Mp angle have shorter dental roots than other patients with open bite.

Table 8. Random Intercept Model for Outcome Variables of the R/C Ratio and Root Length in the Open-Bite Group

	R/C Ratio		Root Length	
Fixed Effect	Estimate (SE)	*P* Value	Estimate (SE)	*P* Value
Mp-SN $>$ 1 SD above the mean	−0.066 (0.021)	**	−0.76 (0.18)	***

** $P < .01$; *** $P < .001$.

To evaluate the dental root morphology in detail, further research using computed tomography will be needed.

CONCLUSIONS

- Patients with open bite have an unfavorable R/C ratio from the incisors to the premolars, with some teeth having short dental roots; these results may be related to loss of OC.
- Patients with open bite with a high Mp angle have shorter dental roots than other patients with open bite.

ACKNOWLEDGMENT

Aya Maeda and Sawako Uehara made equal contributions to this manuscript and should both be considered first authors.

REFERENCES

1. Miyazaki H, Notegi E, Yatabe K, Yamaguchi H, Maki Y. A study of occlusion in elderly Japanese over 80 years with at least 20 teeth. *Gerodontology*. 2005;22:206–210.
2. de Freitas MR, Beltrão RT, Janson G, Henriques JF, Cançado RH. Long-term stability of anterior open bite extraction treatment in the permanent dentition. *Am J Orthod Dentofacial Orthop*. 2004;125:78–87.
3. Harris EF, Butler ML. Patterns of incisor root resorption before and after orthodontic correction in cases with anterior open bites. *Am J Orthod Dentofacial Orthop*. 1992;101: 112–119.
4. Arntsen T, Kjær I, Sonnesen L. Lengths of the maxillary central incisor, the nasal bone, and the anterior cranial base in different skeletal malocclusions. *Acta Odontol Scand*. 2009;9:1–6.
5. Sringkarnboriboon S, Matsumoto Y, Soma K. Root resorption related to hypofunctional periodontium in experimental tooth movement. *J Dent Res*. 2003;82:486–490.
6. Miyawaki S, Araki Y, Tanimoto Y, Katayama A, Fujii A, Imai M, Takano-Yamamoto T. Occlusal force and condylar motion in patients with anterior open bite. *J Dent Res*. 2005;84:133–137.
7. Kiliaridis S, Mejersjö C, Thilander B. Muscle function and craniofacial morphology: a clinical study in patients with myotonic dystrophy. *Eur J Orthod*. 1989;11:131–138.
8. Prahl-Andersen B, Oerlemans J. Characteristics of permanent teeth in persons with trisomy G. *J Dent Res*. 1976;55: 633–638.
9. Lähdesmäki R, Alvesalo L. Root growth in the permanent teeth of 45,X/46,XX females. *Eur J Orthod*. 2006;28:339–344.
10. Al-Jamal GA, Hazza'a AM, Rawashdeh MA. Crown-root ratio of permanent teeth in cleft lip and palate patients. *Angle Orthod*. 2010;80:1122–1128.
11. Smith BG, Knight JK. An index for measuring the wear of teeth. *Br Dent J*. 1984;156:435–438.
12. Hölttä P, Nyström M, Evälahti M, Alaluusua S. Root-crown ratios of permanent teeth in a healthy Finnish population assessed from panoramic radiographs. *Eur J Orthod*. 2004; 26:491–497.
13. Lind V. Short root anomaly. *Scand J Dent Res*. 1972;80: 85–93.
14. Lähdesmäki R, Alvesalo L. Root lengths in 47,XYY males' permanent teeth. *J Dent Res*. 2004;83:771–775.
15. Brook AH, Holt RD. The relationship of crown length to root length in permanent maxillary central incisors. *Proc Br Paedod Soc*. 1978;8:17–20.
16. Rejebin GP. A statistical correlation of individual tooth size distortions on orthopantomographic radiography. *Am J Orthod*. 1979;75:525–534.
17. Dahlberg G. Statistical methods for medical and biological students. London, UK: Allen and Unwin; 1940.
18. Fukami A, Saitoh I, Inada E, et al. A reproducibility method to test lip-closing strength in preschool children. *Cranio*. 2010;28:232–237.
19. Tu YK, Gilthorpe MS, Griffiths GS, Maddick IH, Eaton KA, Johnson NW. The application of multilevel modeling in the analysis of longitudinal periodontal data–part I: absolute levels of disease. *J Periodontol*. 2004;751:127–136.
20. Yamanouchi S, Ishihara K, Shirato Y, Sato K, Mitani H. Facial pattern of the present day Japanese associated with normal occlusion. *J Jpn Orthod Soc*. 1995;54:93–101.
21. Stramotas S, Geenty JP, Petocz P, Darendeliler MA. Accuracy of linear and angular measurements on panoramic radiographs taken at various positions in vitro. *Eur J Orthod*. 2002;24:43–52.
22. Hölttä P, Hovi L, Saarinen-Pihkala UM, Peltola J, Alaluusua S. Disturbed root development of permanent teeth after pediatric stem cell transplantation. Dental root development after SCT. *Cancer*. 2005;103:1484–1493.
23. Enokida M, Kaneko S, Yanagishita M, Soma K. Inference of occlusal stimuli on the remodelling of alveolar bone in a rat hypofunction-recovery model. *J Oral Biosci*. 2005;47: 321–334.
24. Iwasaki-Hayashi Y, Iida J, Warita H, Soma K. Effects of occlusal hypofunction on the microvasculature and endothelin expression in the periodontal ligaments of rat molars. *Orthod Waves*. 2001;60:373–380.
25. Tanaka A, Iida J, Soma K. Effect of hypofunction on the microvasculature in the periodontal ligament of the rat molar. *Orthod Waves*. 1998;57:180–188.
26. Shimomoto Y, Chung CJ, Iwasaki-Hayashi Y, Muramoto T, Soma K. Effects of occlusal stimuli on alveolar/jaw bone formation. *J Dent Res*. 2000;86:47–51.