Original Article

Evaluation of maxillary central incisors on the noncleft and cleft sides in patients with unilateral cleft lip and palate—Part 2: *Relationship between root resorption, horizontal tooth movement, and quantity of grafted autogenous bone*

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ABSTRACT

Objective: To evaluate the relationship between external apical root resorption (EARR) of the maxillary central incisors (U1), horizontal orthodontic tooth movement, and quantity of grafted bone in subjects with unilateral cleft lip and palate (UCLP) over an average duration of 8 years.

Materials and Methods: Thirty subjects with UCLP were evaluated for EARR of U1 after edgewise treatment (T2). The teeth were classified as having no EARR, moderate EARR (combined into "no/moderate" EARR), or severe EARR. Frontal cephalometric radiographs acquired at eruption of U1 (T0), less than 6 months before secondary alveolar bone grafting (T1), and T2 were evaluated to determine the horizontal inclination (U1-axis angle) and distance of the root apex from the median line (U1-root–VL distance). On the cleft side, the quantities of grafted bone at less than 12 months postsecondary bone grafting and at T2 were evaluated using the alveolar bone graft (ABG) scale.

Results: Cleft-adjacent teeth exhibited more severe EARR than did teeth on the noncleft side. The cleft side exhibited greater changes in U1-axis angle and U1-root–VL distance between T0 and T2 than did the noncleft side. On the cleft side, the ABG score at T2 in the severe EARR group was significantly lower than that in the no/moderate EARR group. These measurements were correlated with EARR grade.

Conclusions: Cleft-adjacent U1 exhibited more severe EARR than did the U1 on the noncleft side, which might be associated with orthodontic treatment-induced changes in horizontal inclination and root apex movement. On the cleft side, severity of EARR may be correlated with the success of ABG. (*Angle Orthod.* 2017;87:863–870.)

KEY WORDS: Root resorption of maxillary central incisors; Horizontal tooth movement; Grafted autogenous bone; UCLP

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Table 1. Sex and Age Distribution of Subjects at Each Evaluation Period and Mean Observation Period

Variable	N/N or Mean ± SD[b]
Sex (male/female, N)	16/14
Age at T0[a] (y)	7.80 ± 0.87
at T1 (y)	10.50 ± 1.51
at T2 (y)	16.49 ± 1.70
Observation period (y)	8.70 ± 1.78

[a] T0 indicates at eruption of central incisors; T1, at less than 6 months prior to secondary bone grafting; T2, after edgewise treatment.
[b] SD indicates standard deviation.

INTRODUCTION

In patients with unilateral cleft lip and palate (UCLP), dental traits such as delayed root formation and tooth development, and short root length might occur with higher frequency on the cleft side than on the noncleft side[1–3] because cleft formation can affect the development of the dentition.[2] These dental abnormalities might complicate treatment planning and affect prosthodontic efforts or orthodontic management—a major concern for orthodontists.

External apical root resorption (EARR) is a common consequence of orthodontic tooth movement.[4] In an extensive review of reports regarding root resorption after orthodontic treatment, factors associated with increased levels of EARR were categorized as biological, mechanical, combined biological and mechanical, and other factors.[4] In patients with UCLP, anterior teeth on the cleft side have been shown to exhibit greater root resorption than those on the noncleft side.[5] In cleft-adjacent central incisors, cervical and apical root resorption is sometimes diagnosed several years after combined orthodontic and surgical therapy.[6,7] It has been suggested that apical root resorption is especially caused by alveolar bone grafting after the age of 12 years, when the vulnerable cervical regions of cleft-adjacent teeth are not protected by a thick layer of bone, causing the teeth to be pressed against the hard cortical layer.[8] Therefore, EARR might be associated with the success of bone grafting and orthodontic tooth movement. However, the relationship among EARR and the position or movement of teeth during orthodontic treatment, cleft width, and outcome of the bone graft on the cleft side is yet unclear.

This study tested the following hypotheses: (1) EARR of maxillary central incisors (U1) on the cleft side is more severe than that on the noncleft side and is associated with horizontal tooth position or orthodontic tooth movement and (2) EARR of U1 on the cleft side is associated with cleft width or the success of the alveolar bone graft.

MATERIALS AND METHODS

This study was approved by the Kagoshima University Ethics Committee (Nos. 519, 589, and 661).

Subjects

Among consecutive patients with CLP treated at the Department of Orthodontics, Kagoshima University Medical and Dental Hospital, Kagoshima, Japan, between 1983 and 2015, 30 patients who met the inclusion and exclusion criteria were enrolled (Table 1). The inclusion criteria were: presence of complete UCLP, orthodontic and surgical treatment for UCLP at the hospital, similar orthodontic treatment in the cleft area in accordance with the following protocol (N = 66): (1) alignment of the cleft-adjacent U1 by lingual inclination or rotation, being careful to avoid movement of the roots into the cleft area, and expansion of the maxillary arch before SBG in cases in which the maxillary dental arch displayed constriction of the minor segment; (2) secondary alveolar bone grafting (SBG) during the mixed dentition; (3) initiation of orthodontic treatment, including edgewise treatment in the graft area, with treatment for cleft-adjacent teeth at 3 months post-SBG in cases requiring tooth movement into the graft area; and (4) edgewise treatment of the maxillary and mandibular permanent teeth. Exclusion criteria were as follows: treatment involving maxillary orthognathic surgery (N = 13), unavailability of radiographs required for this study (N = 14), presence of cleft-adjacent lateral incisors or cleft-adjacent supernumerary teeth in the major segment (N = 2), root apex of U1 not closed before SBG (Nolla developmental stages[9] <9; N = 4), congenitally missing U1 (N = 1), and crown and root length not measurable (eg, when the apex was not imaged (N = 1) or the crown was fitted with a large dental prosthesis (N = 1).

Evaluation of Occlusal Radiographs

Evaluation of EARR. Occlusal radiographs of the maxillary anterior teeth, including the cleft area, were acquired by radiologists using a standard radiologic (long-cone) technique. The central ray was directed at a vertical angulation of +75° and a horizontal angulation of 0°, with the bridge of the nose lying below nasion and toward the center of the film. Occlusal radiographs acquired after edgewise treatment (T2) were evaluated. Root resorption was evaluated by a modified method[10] derived from the original method of Malmgren et al.[11] (Figure 1). Teeth without EARR (grade 0) or with EARR of grade 1 or 2 were assigned to the no/moderate EARR group, while those with EARR of grade 3 or 4 were assigned to the

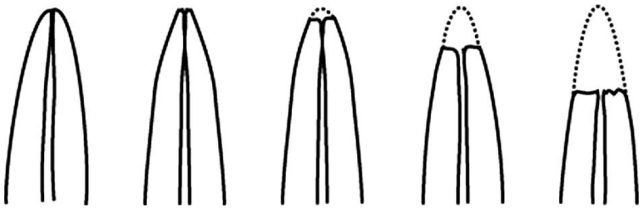

Figure 1. Evaluation of external apical root resorption using a scoring system derived from the Malmgren classification: grade 0, no root resorption; grade 1, mild resorption, root with normal length and irregular contour only; grade 2, moderate resorption with small area of root loss and root apex exhibiting an almost straight contour; grade 3, accentuated resorption with loss of almost one-third of root length; grade 4, extreme resorption with loss of more than one-third of root length.

severe EARR group. All evaluations were performed by the same author. Inter- and intraexaminer reliabilities of EARR grading of 60 U1 on the 30 occlusal radiographs were evaluated using kappa statistics by reexamining the radiographs after a minimum interval of 2 months. The kappa values for inter- and intraexaminer reliabilities for EARR grading were 0.727 and 0.917, respectively, while those for patient categorization into the severe and no/moderate EARR groups were 0.864 and 1.00, respectively.

Evaluation of cleft width and alveolar bone graft scores. Presurgical cleft width was evaluated using occlusal radiographs acquired less than 6 months before SBG (T1). Cleft width was determined at the widest point by visual inspection (Figure 2).[12] The quantity of bone tissue at the cleft site post-SBG was

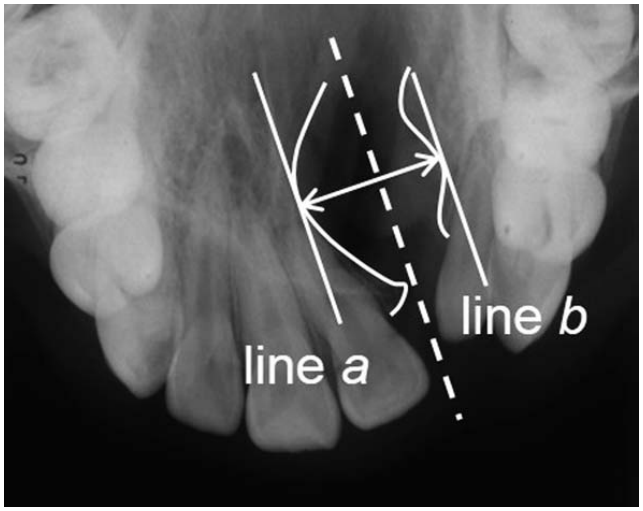

Figure 2. Evaluation of presurgical cleft width. White dotted line, virtual line along the major axis of the cleft; line *a*, line parallel to the white dotted line and touching the outermost bone of the major segment; line *b*, line parallel to the white dotted line and touching the outermost bone of the minor segment. Cleft width (white arrow) was measured along the line perpendicular to lines *a* and *b*.

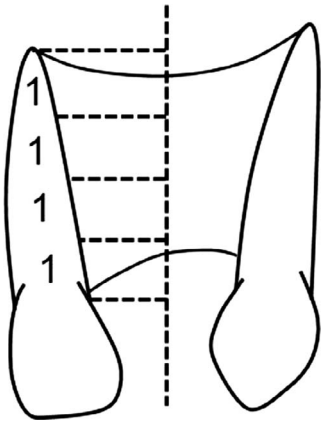

Figure 3. Evaluation of alveolar bone graft grade on a 4-point scale. Each root quarter was scored as follows: 0, bone present on less than half the root surface; 0.5, bone present on more than half the root surface but fails to reach the midline; and 1, bone present on more than half the root surface and extends up to the midline, as described by Witherow et al.[13]

evaluated using occlusal radiographs acquired at 3–12 months post-SBG and at T2 by means of alveolar bone graft (ABG) scores (0–4 points) assigned on the side of cleft-adjacent U1 (Figure 3).[13]

Evaluation of Frontal Cephalometric Radiographs

Frontal cephalometric radiographs of all subjects acquired at eruption of the cleft-adjacent incisors (T0), T1, and T2 were evaluated for dentofacial morphological characteristics. The radiographs were traced by the authors, and WinCeph 9.0 software (Compudent, Koblenz, Germany) was used to determine the angle. Distances were measured using digital calipers.

Figure 4 presents the frontal cephalometric variables evaluated in this study. Two reference lines: a horizontal line (HL) connecting the right and left latero-orbitale points and a vertical line (VL) through the center of the crista galli perpendicular to the HL were traced for performing vertical and horizontal measurements. The internal angle between the HL and central incisal axis (CA) was defined as the U1-axis angle (angle *a*). The horizontal distance between the VL and root apex or crown edge of U1 was defined as the U1-root–VL (c) or U1-crown–VL (b) distance, respectively.

To assess intraexaminer reproducibility and reliability of the measurements, 30 randomly selected frontal cephalometric radiographs (T0, T1, and T2; 10 each) were retraced after a minimum interval of 2 months. Evaluation of discrepancies in measurement between the original and retraced frontal radiographs (matched paired *t*-test) revealed no statistically significant differences.

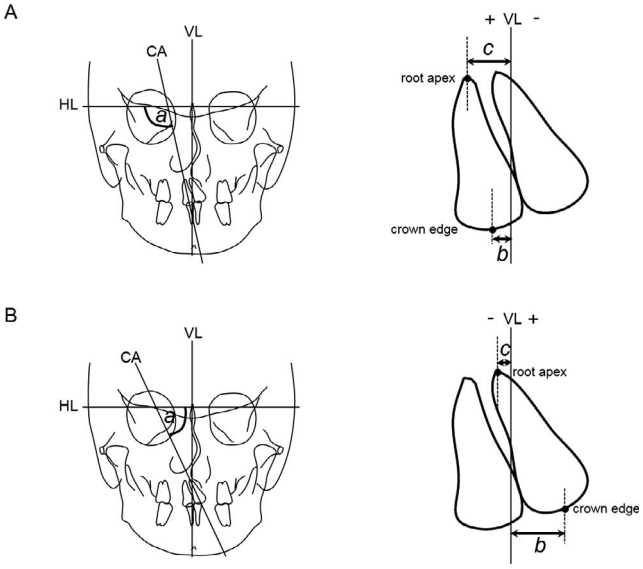

Figure 4. Cephalometric analysis. A, noncleft side; B, cleft side; a, long-axis angle (°); b, U1-crown–VL distance (mm); c, U1-root–VL distance (mm); U1, maxillary incisor; VL, vertical line; HL, horizontal line; CA, central incisal axis.

Statistical Analysis

Differences in variables between the no/moderate and severe EARR groups were evaluated by the Mann-Whitney *U*-test. Significance of intergroup differences in categorical variables was determined using Fisher's exact test. Significance of differences in EARR grade of U1 between the noncleft and cleft sides in each patient was determined by the paired *t*-test. The association and correlation coefficient between each of the variables and the five grades of EARR were determined by Spearman rank-order correlation analysis. The probability of significance was calculated for each comparison, and $P < .05$ was considered statistically significant. Correlations were also considered significant at $P < .05$. Statistical tests were performed using SPSS version 24.0 for Windows (IBM, Armonk, NY).

RESULTS

Of the 30 U1 each on the noncleft and cleft sides, 26 (86.7%) and 18 (60.0%), respectively, were assigned to the no/moderate EARR group. In the severe EARR group, cleft-adjacent teeth were significantly more plentiful than teeth on the noncleft side (Table 2, $P = .039$).

There were significant differences in almost all cephalometric measurements between the cleft and noncleft sides at T0, T1, and T2. The cleft and noncleft sides also differed significantly in terms of changes in almost all measurements between T0 and T1, T1 and T2, and T0 and T2. The cleft side exhibited a greater total variation in U1-axis angle between T0 and T2 than did the noncleft side. On the cleft side, the severe EARR group exhibited lower ABG scores at T2 than did the no/moderate EARR group ($P = .004$; Table 3). However, in terms of other measurements, there were no significant differences between the two groups on either side.

The EARR grades were significantly and negatively correlated with cephalometric variables (U1-axis angles and U1-root–VL distances at T0 and T1). Changes (T1 to T2 and T0 to T2) and total variation (T0 to T2) in the U1-axis angle and U1-root–VL distance were significantly and positively correlated with EARR. However, there were no significant correlations between EARR grade and cephalometric parameters on either side. In contrast, EARR grade of the cleft-adjacent U1 was negatively correlated with ABG scores at T2 (Table 4).

DISCUSSION

The present cohort was chosen from among consecutive patients treated. All patients were treated in accordance with the protocol commonly used for treatment of cleft lip and palate and were selected on the basis of fulfilment of inclusion and exclusion criteria for evaluation of U1 EARR. However, the present sample size was relatively small for some statistical tests. Therefore, we performed post hoc power calculations (1-β) for all items that exhibited statistically significant differences or correlations ($P < .05$). The statistical powers (1-β) of all items or measurements were less than 0.80, excluding comparison of total variation in U1-root–VL distance on the noncleft side

Table 2. Distribution of External Apical Root Resorption Grade

Grade[a]	Total Teeth (n = 60)	Noncleft Side Teeth (n = 30)	Cleft Side Teeth (n = 30)	Group	Total Teeth (n = 60)	Noncleft Side Teeth (n = 30)	Cleft Side Teeth (n = 30)	*P* Value[b]
0	1	1	0	No/moderate	44	26	18	.039*
1	9	8	1	(grades 0–2)				
2	34	17	17					
3	13	4	9	Severe	16	4	12	
4	3	0	3	(grades 3 and 4)				

[a] Indicates according to a score system derived from the Malmgren classification.[11]
[b] Indicates Fisher's exact test.
*$P < .05$.

Table 3. Comparison of Frontal Cephalometric Measurements, Cleft Width, and ABG Scores on Each Side Between the No/Moderate and Severe External Apical Root Resorption Groups

	Noncleft side							Cleft side							Noncleft vs Cleft sides
	All Teeth (n = 30)		No/Moderate Group (n = 26)		Severe Group (n = 4)			All Teeth (n = 30)		No/Moderate Group (n = 18)		Severe Group (n = 12)			All Teeth
Measurements	Mean	SD	Mean	SD	Mean	SD	*P* Value	Mean	SD	Mean	SD	Mean	SD	*P* Value	*P* value
At T0[a]															
U1-axis angle (°)	90.77	6.34	91.37	6.59	86.88	1.89	NS	72.05	6.97	72.17	7.64	71.87	6.60	NS	< .001***
U1-crown–VL distance (mm)	5.63	1.93	5.57	1.99	6.07	1.64	NS	5.65	2.19	5.82	2.36	5.41	1.97	NS	NS
U1-root–VL distance (mm)	5.74	1.82	5.85	1.82	5.02	1.94	NS	−0.63	1.87	−0.43	2.06	−0.94	1.59	NS	< .001***
At T1															
U1-axis angle (°)	94.48	4.52	94.38	4.56	95.10	4.83	NS	72.60	8.32	72.56	9.37	72.67	6.85	NS	< .001***
U1-crown–VL distance (mm)	3.96	2.44	4.07	2.47	3.30	2.47	NS	6.09	3.11	5.96	2.96	6.29	3.45	NS	.005**
U1-root–VL distance (mm)	5.61	2.13	5.69	2.02	5.08	3.07	NS	−0.09	2.08	−0.27	1.57	0.19	2.74	NS	< .001***
At T2															
U1-axis angle (°)	94.27	5.41	94.03	5.74	95.85	2.28	NS	81.66	6.47	80.81	6.61	83.09	6.24	NS	< .001***
U1-crown–VL distance (mm)	3.72	2.44	3.80	2.03	3.18	4.69	NS	5.15	2.45	4.94	2.61	5.45	2.28	NS	.014*
U1-root–VL distance (mm)	4.84	2.07	4.88	1.69	4.53	4.19	NS	2.16	2.75	1.76	2.94	2.77	2.44	NS	< .001***
Change between T0 and T1															
U1-axis angle (°)	3.71	6.38	3.02	6.19	8.23	6.52	NS	0.55	6.64	0.39	7.00	0.80	6.37	NS	.049*
U1-crown–VL distance (mm)	−1.67	2.58	−1.50	2.72	−2.77	0.98	NS	0.44	2.49	0.14	2.20	0.88	2.92	NS	.001**
U1-root–VL distance (mm)	−0.14	1.78	−0.17	1.72	0.06	2.42	NS	0.55	1.74	0.16	1.65	1.12	1.79	NS	NS
Change between T1 and T2															
U1-axis angle (°)	−0.21	5.69	−0.35	5.78	0.75	5.71	NS	9.06	8.78	8.14	6.49	10.43	11.62	NS	< .001***
U1-crown–VL distance (mm)	−0.25	2.76	0.27	2.39	−0.12	5.11	NS	−0.94	2.89	−1.02	2.69	−0.83	3.30	NS	NS
U1-root–VL distance (mm)	−0.77	2.22	−0.70	1.81	−0.55	4.52	NS	2.25	2.45	2.03	2.53	2.58	2.38	NS	< .001***
Change between T0 and T2															
U1-axis angle (°)	3.50	7.16	2.66	7.27	8.98	3.02	NS	9.61	8.46	8.53	7.69	11.23	9.63	NS	.014*
U1-crown–VL distance (mm)	−1.92	2.62	−1.77	2.29	−2.89	4.59	NS	−0.51	2.64	−0.88	2.89	0.04	2.21	NS	.044*
U1-root–VL distance (mm)	−0.90	2.45	−0.97	2.06	−0.49	4.74	NS	2.80	2.81	2.19	3.14	3.71	2.00	NS	< .001***
Total change between T0 and T2 (sum of absolute values of change)															
U1-axis angle (°)	10.11	5.31	9.83	5.27	11.93	6.05	NS	15.10	8.62	13.53	8.56	17.44	8.54	NS	.014*
U1-crown–VL distance (mm)	4.62	2.93	4.31	2.85	6.62	3.14	NS	4.06	3.01	3.55	2.57	4.81	3.55	NS	NS
U1-root–VL distance (mm)	3.34	1.68	3.05	1.43	5.22	2.17	.020*[a]	4.17	2.01	3.89	2.19	4.58	1.70	NS	NS
Cleft width (mm)	–	–	–	–	–	–	–	–	–	6.74	2.43	7.59	2.92	NS	–
ABG score (0–4) at 3–12 mo post-SBG	–	–	–	–	–	–	–	–	–	3.53	0.65	3.13	0.74	NS	–
ABG score (0–4) at T2	–	–	–	–	–	–	–	–	–	3.61	0.56	2.88	0.64	.004**	–

[a] T0 indicates at eruption of central incisors; T1, less than 6 months prior to secondary bone grafting; T2, after edgewise treatment; VL, vertical line; ABG, alveolar bone graft; SD, standard deviation.

[b] The *P* value, derived using the Mann-Whitney *U* test, was considered insignificant because the calculated power was <.8.

* $P < .05$; ** $P < .01$; *** $P < .001$; NS, not significant .

Table 4. Correlation between EARR and Cephalometric Variables

Variables	Total (n = 60) EARR Grade (0–4)	Noncleft Side (n = 30) EARR Grade (0–4)	Cleft Side (n = 30) EARR Grade (0–4)
EARR[a] grade (0–4)	NS (1.000)	NS (1.000)	NS (1.000)
At T0			
U1-axis angle (°)	−0.404**	NS	NS
U1-crown–VL distance (mm)	NS	NS	NS
U1-root–VL distance (mm)	−0.433**	NS	NS
At T1			
U1-axis angle (°)	−0.369**	NS	NS
U1-crown–VL distance (mm)	NS	NS	NS
U1-root–VL distance (mm)	−0.318*	NS	NS
At T2			
U1-axis angle (°)	NS	NS	NS
U1-crown–VL distance (mm)	NS	NS	NS
U1-root–VL distance (mm)	NS	NS	NS
Change between T0 and T1			
U1–axis angle (°)	NS	NS	NS
U1-crown–VL distance (mm)	NS	NS	NS
U1-root–VL distance (mm)	NS	NS	NS
Change between T1 and T2			
U1-axis angle (°)	0.275*	NS	NS
U1-crown–VL distance (mm)	NS	NS	NS
U1-root–VL distance (mm)	0.381*	NS	NS
Change between T0 and T2			
U1-axis angle (°)	0.304*	NS	NS
U1-crown–VL distance (mm)	NS	NS	NS
U1-root–VL distance (mm)	0.447***	NS	NS
Total change between T0 and T2 (sum of absolute values of change)			
U1-axis angle (°)	0.280*	NS	NS
U1-crown–VL distance (mm)	NS	NS	NS
U1-root–VL distance (mm)	0.319*	NS	NS
Cleft width (mm)	–	–	NS
ABG score (0–4) at 3–12 mo post-SBG	–	–	NS
ABG score (0–4) at T2	–	–	−0.487**

[a] EARR indicates external apical root resorption; T0, at eruption of central incisors; T1, less than 6 months prior to secondary bone grafting; T2, after edgewise treatment; VL, vertical line; SD, standard deviation; ABG, alveolar bone graft.

*$P < .05$; **$P < .01$; ***$P < .001$; NS, not significant. P value derived by using Spearman rank-order correlation analysis.

between the two EARR groups (Table 3; $P = .02$). We considered only comparisons with P values $<.05$ with power calculation >0.8 to be significant.

In a previous study involving nonsyndromic adults, the prevalence of orthodontic treatment-induced EARR of U1 was 58%.[14] In another study, the proportion of teeth with severe EARR after orthodontic treatment was 25%.[15] Of the 60 U1s evaluated in the present study, 43 and 16 exhibited moderate (71.7%) and severe (26.7%) EARR, respectively, which suggests that patients with UCLP have a similar risk of developing orthodontic treatment-induced EARR in the U1 as do nonsyndromic patients. On the other hand, relative to teeth on the noncleft side, a significantly greater number of cleft-adjacent teeth exhibited severe EARR. Unusual root morphology, such as short, blunt, or pipette-shaped roots, has been discussed as a possible risk factor for EARR, especially for severe EARR.[16–18] In part 1 of this study, it was clear that root length of U1 on the cleft side was shorter than that on the noncleft side at T1. These results suggest that the presence of short roots in cleft-adjacent U1 might be one of the risk factors for severe EARR during orthodontic treatment.

In the present study, cleft-adjacent U1 exhibited horizontal inclination with root deviation in the opposite direction of the cleft at eruption, with subsequent changes in U1-axis angle and U1-root–VL distance being greater than those in U1 on the noncleft side. That these changes were related to EARR grade in patients with UCLP suggests that orthodontic treatment-induced root movement in the direction of the cleft and improvement in horizontal inclination might cause severe EARR in the cleft-adjacent U1. Gerner et al.[19] reported that resorptive injuries exhibit several traits similar to those of external inflammatory resorption, including progression and localization of resorption in the cervical area. Periodontal tissue damage is a causal factor for root resorption.[20,21] Proximity of dental roots to the cortical bone is another orthodontic

treatment-related risk factor for EARR.[22,23] Taken together, these findings suggest that movement of cleft-adjacent U1 roots to the cleft edge might lead to root resorption after subsequent orthodontic treatment.

We evaluated the grafted bone at 3–12 months post-SBG and at T2. Occlusal radiographs at approximately 3 and 6–12 months post-SBG were acquired to observe the grafted bone, the volume of which has been reported to decrease significantly until 3 months post-SBG.[24] Therefore, we evaluated ABG scores at an early phase of the post-SBG period by using the earliest of occlusal radiographs acquired 3–12 months post-SBG. Orthodontic treatment after SBG might help close the gap in the maxillary dental arch, and the "functional stress" imposed by orthodontic treatment might influence the volume of grafted bone and prevent its resorption.[24,25] For these reasons, orthodontists often begin treatment for movement of cleft-adjacent teeth in the direction of the grafted bone after an average duration of 3 months post-SBG.[7,8] In the present study, of the 18 patients with no/moderate EARR and 12 patients with severe EARR, 12 (66.7%) and 6 (50.0%) patients, respectively, began orthodontic treatment within 3 months post-SBG to prevent resorption of the grafted bone ($P = .458$; Fisher's exact test). Therefore, the timing of orthodontic movement of cleft-adjacent teeth after SBG does not appear to be associated with EARR.

ABG scores of cleft-adjacent U1s less than 1 year after edgewise treatment were not correlated with EARR. However, EARR grade was correlated with ABG scores after edgewise treatment. Additionally, ABG scores after edgewise treatment were negatively correlated with cleft width (correlation coefficient, -0.476; $P < .008$; data not shown). The present results demonstrate that a long-term decrease in grafted autogenous bone quantity after SBG might result in EARR, especially in patients with greater cleft widths.

CONCLUSIONS

- Cleft-adjacent U1 exhibited higher EARR grades than did central incisors on the noncleft side.
- Relative to noncleft-adjacent U1, cleft-adjacent U1 exhibited lower horizontal inclinations, with the root apex shifted to the noncleft side. These parameters were correlated with EARR grade.
- Among cleft-adjacent U1, teeth with severe EARR exhibited significantly lower ABG scores after edgewise treatment than did those with no/moderate EARR.

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