RESEARCH

Alveolar bone loss around incisors in Class I bidentoalveolar protrusion patients: a retrospective three-dimensional cone beam CT study

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Objectives: The aim of this study was to test the null hypothesis that there is no difference in the alveolar bone thickness, bone loss or incidence of fenestrations between upper and lower incisors in skeletal Class I bidentoalveolar protrusive patients before orthodontic treatment.

Methods: Three-dimensional (3D) cone beam CT (CBCT) images were taken of 24 patients from the Republic of Korea (17 females and 7 males). Reformatted CBCT images were used to measure labial and lingual alveolar bone thickness (ABT) of the 4 upper incisors and 4 lower incisors of the 24 patients (total $n = 192$ incisors) at every 1/10 of root length (Level 0, cemento-enamel junction (CEJ) area; Level 10, root apex area) as well as alveolar bone area (ABA) and alveolar bone loss (%BL) rate to dental root length. The numbers of fenestration teeth were also tallied.

Results: All anterior teeth were supported by <1 mm of ABT on the labial surfaces up to root length Level 8. ABA was statistically greater on the lingual aspect than the labial aspect in lower incisors. The %BL was 26.98% in the lower labial region, 19.27% in upper labial aspect and most severe on the lower lingual plate 31.25% compared with the labial plate. There were no significant differences in %BL between subgroups when categorized by sex or age. Fenestrations were 1.37 times more frequent on lower incisors (37) than upper incisors (27).

Conclusion: The null hypothesis was rejected, confirming that incisor periodontal support is poor and alveolar bone loss is severe even prior to the start of orthodontic treatment. Careful diagnosis using 3D CBCT images is needed to avoid iatrogenic degeneration of periodontal support around anterior teeth, particularly in the lower lingual bone plate region.

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Keywords: alveolar bone loss; cone beam computed tomography; fenestration; bidentoalveolar protrusion; extraction

Introduction

Bidentoalveolar protrusion is a common chief concern in Asians seeking orthodontic treatment and extraction of premolars is often necessary to create room for the retraction of anterior teeth. Because torque control of

anterior teeth is very important during retraction, a biological challenge arises because patients with narrow alveolar bone width or severe skeletal discrepancies are likely to exhibit severe iatrogenic loss of periodontal support when the incisor apices are about to challenge the “orthodontic walls” of the dense cortical plates during retraction.¹ It is imperative to complete a comprehensive clinical and radiographic examination for identification of any pre-existing fenestrations, alveolar bone loss or dehiscence prior to initiation of any treatment in order to avoid excessive retraction of

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incisors and prevent exacerbation of any periodontal problems.^{2,3}

To date, there are few articles documenting the status of the periodontium and supporting bone in patients prior to the initiation of orthodontic treatment. Fuhrmann's⁴ research concluded that there is a general overestimation of the labiolingual bone width on the lateral cephalogram when compared with physical measurements of the actual specimens. In that study, it was demonstrated that 80% of defects identifiable on CT scan images were not readily visible on the lateral cephalograms. Therefore, while a lateral cephalogram can be a valuable tool for identifying gross craniofacial anatomical relationships, its inherent two-dimensional (2D) perspective presents significant limitations for evaluating periodontal conditions, especially in the anterior teeth. Moreover, cephalometry does not extend the ability to diagnose dehiscences of individual mandibular incisors. Three-dimensional (3D) analysis of specific regions of interest using cone beam CT (CBCT) is currently the best tool available for identifying these bone-supporting periodontal conditions.^{3,5,6}

Using pre-treatment CBCT records of patients from the Republic of Korea with bidentoalveolar protrusion, the aims of this study were: (1) to evaluate of alveolar bone thickness, (2) to investigate vertical alveolar bone loss rate, and (3) to enumerate existing fenestrations on alveolar bone.

Materials and methods

Patients

Pre-treatment records of 24 patients from the Republic of Korea (17 females and 7 males) diagnosed as bidentoalveolar protrusive without vertical problem were used in this study. The mean age of the patients was

20.4 years (range, 12–32 years). The patients had complete or nearly complete dentition and minimal to moderate crowding. Exclusion criteria were severe dental crowding, radiographic signs of periodontal diseases (as diagnosed by intraoral radiographs and CBCT data), endodontic treated teeth and rotated teeth. Lateral cephalograms were employed to establish skeletal Class I and dental relationships. Pre-treatment CBCT scans were taken by the Department of Oral and Maxillofacial Radiology at Kyung Hee University. A CBCT scan (Alphard Vega; Asahi Roentgen Ind. Co., Ltd, Kyoto, Japan) was taken on each patient using the manufacturer's recommended parameters of a 102 × 102 mm field of view, 80 kVp, 10 mA, 17 s scan time, 0.2 mm slice thickness and 0.2 mm³ isotropic voxel size. CBCT data sets were saved in digital imaging and communications in medicine (DICOM) format and reconstructed into 3D images using the On Demand software program (Cyber-Med Inc., Seoul, Republic of Korea). Cross-sectional slices through each of the 4 upper incisors and each of the 4 lower incisors in the 24 patients were generated to show labial and lingual surfaces of the total 192 incisors. The slices were generated at the putative centre where the tooth exhibited the greatest distance labiolingually. This report and associated data was reviewed by the Institutional Review Board (IRB) at The Catholic University of Korea (CUMC11U045).

Measurements

The reference points, lines and measurement variables used in this study (Figure 1 and Table 1) were modified from previous reports.^{1,3,7–10} Two examiners (K-YN and J-HK) were calibrated for alveolar bone measurements and performed all of the measurements on the CBCT images using the same computer and screen

Figure 1 Schematic illustrations of (a) upper and (b) lower reference points, lines and measurement variables used in this study. Alveolar bone area, $ABA = [(a + b) \times c] / 2 \text{ mm}^2$; level 0 = line perpendicular to root axis on the cemento-enamel junction area; level 10 = line perpendicular to root axis on the root apex area; F, fenestration; UABL, upper anterior bone loss; UPBL, lower posterior bone loss

Table 1 Definitions of measurement used in this study

Measurement variables	Definition
UAABTUPABT	Upper anterior or posterior distance from root surface to cortical bone at each root level (Level 0 to 10)
LAABTLPABT	Lower anterior or posterior distance from root surface to cortical bone at each root level (Level 0 to 10)
%UABL,%UPBL	Percentage of upper anterior or posterior bone loss to root length
%LABL,%LPBL	Percentage of lower anterior or posterior bone loss to root length
UAABA, UPABA (mm ²)	Upper anterior or posterior alveolar bone area: area from gathering small trapezoid between root levels in cross-sectioned image
LAABA, LPABA (mm ²)	Lower anterior or posterior alveolar bone area: area from gathering small trapezoid between root levels in cross-sectioned image
FN	Tooth fenestration number

(resolution of 1920 × 1440 pixels) under ambient room lighting conditions. Images were generated parallel to the tooth axis in the axial, coronal and sagittal planes.

The sagittal plane of the incisor traversing through the midpoint of incisor edge–root apex was used for evaluation (schematically illustrated in Figures 1 and 2).

Figure 2 CBCT cross-sectional slices of measurement variables on teeth studied. (a) #11, (b) #21, (c) #31, (d) #41. * on (a) denotes location of incisive canal

Table 2 Cephalometric characteristics of the samples

Measurement	Male		Female		Total		p-value
	Mean	Range	Mean	Range	Mean	Range	
Age (years)	19.86	14–32	19.94	12–26	20.3	12.5–32.8	0.095
SNA (°)	80.57	77.86–85.72	79.90	71.53–87.82	80.1	71.5–87.8	0.162
SNB (°)	76.35	72.96–80.61	76.75	67.26–84.54	76.6	67.3–84.5	0.510
ANB difference (°)	4.22	1.77–5.3	3.15	0.12–5.51	3.5	0.1–5.5	0.161
FMA (°)	28.41	22.02–35.98	28.36	20.48–36.23	28.4	20.5–36.2	0.625
FMIA (°)	52.46	38.52–65.11	48.66	40.74–63.96	49.8	38.5–65.1	0.294
IMPA (°)	99.13	89.73–112.62	102.98	93.41–111.04	101.9	89.7–112.6	0.449
U1 to FH (°)	119.37	115.75–122.77	122.04	112.26–140.15	121.3	112.3–140.2	0.672
U1 to SN (°)	111.07	105.1–117.42	112.95	98.45–131.11	112.4	98.5–131.1	0.231
Interincisal angle (°)	113.09	99.54–127.82	106.62	87.93–120.33	108.5	87.9–127.8	0.607

ANB, angle between point A, nasion, and point B; FMA, Frankfort plane to mandibular plane angle; FMIA, Frankfort plane to mandibular incisor angle; IMPA, mandibular incisor to mandibular plane angle; SNA, sella nasion to point A angle; SNB, sella nasion to point B angle; U1 to FH, Frankfort plane to maxillary incisor angle; U1 to SN, sella nasion to maxillary incisor angle.

The distance from root surface to cortical plate perpendicular to root axis [alveolar bone thickness (ABT)] was recorded at every 1/10 of root length on the lingual and labial aspects [level 0, cemento-enamel junction (CEJ) area; level 10, root apex area]. Distance from CEJ to root apex in the sagittal view was used as the overall root length. Alveolar bone area (ABA) (measured in mm²) was calculated from ABT and root length (Figure 1). For situations where the lingual CEJ was not at the same level as the labial CEJ using the longitudinal tooth axis, the lower level was chosen as the CEJ of the teeth. Abbreviations used in this study to quantify bone loss are defined in Table 1. Vertical alveolar bone loss rate to dental root length (%BL) was described as a percentage value. The measurement and calculation was designated as %UABL, %UPBL, %LABL, or %LPBL according to the position (UA, upper anterior; UP, upper posterior; LA, lower anterior; LP, lower posterior). The small section between root levels was assumed to have a trapezoid shape. The sum of small sections was used to evaluate upper and lower or labial and lingual differences. Fenestrations in this study were determined as an opening through the alveolar bone which exposed parts of the root surface (Figure 1). The sample was further divided into 4 subgroups by sex (17 females and 7 males) and age (12 teenagers and 12 patients aged over 20 years) for statistical comparison. All teeth positions were described using the FDI World Dental Federation Two-Digit Notation (International) system.

Statistical analysis

The SAS/STAT[®] software statistical analysis package (SAS Institute Inc., Cary, NC) was used for all analyses. Intraoperator measurement error was tested by randomly selecting 8 of the 24 sample patient data sets and remeasuring the values 2 weeks apart. Mean value and standard deviation and frequency were used as the variables. Interoperator variability was determined using a Pearson's correlation coefficient analysis with additional re-measurements (2 weeks after the initial measurement) of 8 random patients selected from the existing 24 patients. A χ^2 test was also performed for

analysing the frequency analysis. Comparisons of the means of subgroups were made using a Student's *t*-test. A *p* < 0.05 level of significance was selected for all tests.

Results

Cephalometric analysis of the sample patients used in this study, described in Table 2, showed that there were no skeletal or dental variations noted in male vs female subjects (*t*-test). A Pearson's correlation coefficient of >0.97 in all variables confirmed that there was very high interobserver reliability in this study.

Alveolar bone thickness (measured in mm)

The ABT of incisors in various root levels is shown in Figures 3 and 4. Generally bone thickness increases in direction from CEJ (Level 0) to root apex (Level 10). Posterior bone thickness is primarily greater than anterior bone thickness in upper and lower teeth. All incisors showed less than 1 mm of ABT on the labial surfaces up to root Level 8 position and this is especially noticeable on lower central incisors.

Figure 3 Upper alveolar bone thickness (mm) measurement at each root level position for individual incisor studied. p, posterior

Figure 4 Lower alveolar bone thickness (mm) measurement at each root level position for individual incisor studied. p, posterior

Alveolar bone area (measured in mm²)

There were two parameters that differed significantly when comparing patients by gender. Posterior ABA (PABA) on teeth #12 and #21 was greater in males than in females (Figure 5). If age was used as the variable factor, only tooth #12 showed a larger PABA area in young patients (aged under 20 years) compared with the older group (aged 20 years or older) ($p < 0.05$) (Figure 6). There were statistically significant area differences between upper and lower incisors ($p = 0.0003$) (Table 3). The mean area of upper incisors was 18.46 mm² (9.13–33.67 mm²), but the lower incisors only showed 12.68 mm² measured area (4.56–21.80 mm²). The most statistically significant difference was noted between the lower labial and lower lingual alveolar support ($p < 0.0001$). While the mean area of lower lingual cross-section measured 17.59 mm², its counterpart lower labial cross-section was only 7.77 mm². Interestingly, the labial area of upper incisors compared with lower incisors did not show any statistically significant difference ($p = 0.201$).

Alveolar bone loss rate

The lingual aspect of tooth #11 exhibited the least percentage of alveolar bone loss (12.5%). By contrast, the %BL of lower incisors was much more severe when

Figure 5 Comparison of alveolar bone area (ABA) (mm²) between male and female patients. MAABA, anterior alveolar bone area in male patients; FAABA, anterior alveolar bone area in female patients; MPABA, posterior alveolar bone area in male patients; FPABA, posterior alveolar bone area in female patients; *, $p < 0.05$

Figure 6 Comparison of alveolar bone area (ABA) (mm²) as a function of age group. YAABA, anterior alveolar bone area in young patients (aged under 20 years); OAABA, anterior alveolar bone area in older patients (aged over 20 years); YPABA, posterior alveolar bone area in young patients; OPABA, posterior alveolar bone area in older patients; Statistical significance (*) $p < 0.05$

compared with the upper incisors (Table 3) and the greatest %BL involvement was identified on the lingual aspect of mandibular central incisors (37.5% on tooth #41, 36.3% on tooth #31). The labial %BL was greater than the rate of lingual %BL in maxillary incisors, but lingual %BL was more severe than labial %BL in mandibular incisors, except for Tooth #42. Significant differences were noted between %LABL (26.98%) and %UABL (19.27%). The total %LPBL (31.25%) was more severe than %UPBL (15.00%). Comparatively, the %BL of all maxillary and mandibular incisors was 17.14% and 29.11%, respectively, resulting in a marked statistically significant value of $p < 0.0001$. Sex and age factors did not show significant differences in any of the variables related to %BL.

Fenestrations

All of fenestrations were observed on the labial aspect except for the lower left lateral incisor. In the upper arch, 27 out of 192 surfaces had fenestrations (14.1 %) compared with 37 out of 192 sites in the lower incisors (19.3%). The lower incisors manifested approximately 1.37 times more fenestrations compared with the upper incisors (Figure 7).

Discussion

In this study, all incisors showed insufficient ABT except for the upper palatal surface. Even though the lingual aspect showed relatively thicker ABT than the labial area, ABT measurements were < 2 mm up to root Level 6 (except for Tooth #22). The clinical consequence is that patients who require maximum anterior retraction for treating bidentoalveolar protrusion may experience problems with cortical bone contact, root resorption or alveolar bone loss.^{11–16} Kim *et al*'s⁶ previous lateral cephalogram study on lower anterior ABT showed similar results to this study. Labial ABT at Level 6 was approximately 0.9 mm. However, there was limitation

Table 3 Comparison of the alveolar bone area of maxillary and mandibular four incisors (mm²) and alveolar bone loss rate (%BL)

Variables	UAABA	LAABA	LPABA	Variables	(%BL)					
Mean	9.04	7.77	17.59		Labial		Sig.	Lingual		Sig.
Range	3.28–16.85	3.53–13.28	4.72–34.20		Mean	Range	0.037	Mean	Range	<0.0001
p-value	0.201			Maxilla	19.27	10–40		15.00	10–25	
		<0.0001		Mandible	26.98	10–70		31.25	17.5–67.5	

LAABA, lower anterior alveolar bone area; LPABA, lower posterior alveolar bone area; Sig. significance; UAABA, upper anterior alveolar bone area.

on their study design such as superimposed images of lateral cephalogram, overestimation and difficulty in individual tooth evaluation.

Kim *et al*³ used 3D data to study ABT in skeletal Class III patients requiring surgery. Their findings showed that ABT at the apex of lower right central incisors averaged 3.45 mm on the buccal aspect and 2.13 mm on the lingual aspect. Interestingly, the analysis of Class I bidento-alveolar protrusion patients in this study showed the opposite results (%LABL was 26.98% and %LPBL was 31.25%). Moreover, the ABT of the same teeth (#41) was different. The difference between studies may be explained by a compensatory inclination of incisors to accommodate the skeletal base discrepancy in Class III patients. All fenestrations except lower left lateral incisor were observed at the labial aspect. The lower incisors manifested many fenestrations, approximately 1.37 times more than the upper incisors. This is a strong argument for orthodontists to be careful regarding buccal-lingual movement of incisors because artefactual representation of the normal alveolar bone crest seen in 2D lateral cephalograms may mask existing fenestrations and dehiscences.⁵

Even though thin bone below 0.5 mm may not be reconstructed through CBCT images, yielding a fenestration which is not there in reality, the fenestration-like area in this study shows possible limitation of bodily

retraction of anterior teeth for orthodontic treatment of protrusion patients.

Several factors influencing accurate measurements of this study include root-crown curvature, incisive canal and CEJ. If a prominent root-crown curvature was observed, the tooth axis was aligned relative to the root instead of the crown. In patients with incisive canals on the lingual aspect of upper central incisors, the lingual bone thickness was measured from root surface to the incisive canals because the continuity of the lingual bone was interrupted on cross-sectional slice views (Figure 2a). Also the volume averaging effect, a well-known CT artefact, might have done the work that makes it very difficult to detect thin bone (<1 mm).¹⁷ However, the small isotropic voxel size (0.2 mm³) of this study made it possible to perform more precise research. A 10 mA CBCT device in this study means a considerable effective dose for the patients. The effective dose of this CBCT was still much lower than spiral CT devices but needs further study in order to get higher resolution images from low effective dose in CBCT analysis.

One of the aims of this study was to assess whether there were any differences in area of the alveolar bone when subgrouped by gender and age. Since area of the alveolar bone is a function of root length, it is important to establish whether there were differences in root length between patients when grouped by either category. That

Figure 7 Frequency of fenestration observed on each tooth. FN, fenestration number

is, if one subgroup has a longer root length than the other subgroup, by default the area of the first group would be larger even though the bone thickness may be equal. Theoretically, upon apex closure and completion of root tip formation, the overall root length does not change except in cases of pathophysiological or iatrogenic root resorption. Hence, younger and older patients alike can be presumed to have relatively equal root length.^{18–20} Similarly, there is no gender difference relative to root length as reported by Alam *et al*¹⁹ in a study of first permanent molars using a sample population of the same race. Even though the difference between genders was negligible in this study, additional information may be gleaned by calculating a bone thickness per unit root length area ratio.

Even though high resolution CBCT images were used, exact absolute quantitative measurements may differ slightly from *in vivo* anatomical bone conditions. In addition, in living patients with scan times of 17 s, the reconstruction process assumes that the patient does not move more than the size of one voxel over the entire scan time. Obviously, pure logical considerations strongly contradict this assumption. Hence, true optical resolution is around one to two line pairs per millimetre owing to patients' motion artefact.

However, since all the CBCT scans were taken on the same machine by the same operator and the digital measurements were shown to be precise and highly repeatable, the relative quantification of bone presence in the buccal and lingual regions of the upper and lower incisors lends great insight into the precarious nature of little bone support in bidentoalveolar protrusive patients.

There is always the pervasive question of how to safely retract lower anterior teeth in extraction cases without causing iatrogenic damage to the root structure or underlying periodontal and bone support in cases of extremely thin alveolus. Anterior segmented osteotomy is a common procedure used to effectively treat bimaxillary protrusion cases.^{21–24} Localized bone corticotomy

procedure is yet another alternative to conventional incisor retraction orthodontic biomechanics.

In this study, a total of 24 patients were used to study the buccal and lingual bone support of 192 teeth. As we continue to accumulate patient data, increasing the number of patients and teeth will increase the power of the study and further confirm the correlations of thin cortical plate thickness in the incisor region to bidentoalveolar protrusion. Additional data of patients categorized by skeletal maxillomandibular discrepancies (*i.e.* Class II and Class III patients) are also in the process of being analysed and will be reported in subsequent articles.

Conclusion

1. The null hypothesis was rejected. There were differences in alveolar bone thickness observed in patients prior to the start of orthodontic treatment. ABA was greater in the mandibular lingual region compared with the labial region. ABA was also greater in the upper incisors than the lower incisors.
2. Differences between sex and age were observed in cross-sectional area values but not in %BL.
3. Vertical %BL was higher in LABL than UABL, and conversely higher in LPBL than UPBL.
4. Fenestration and alveolar bone loss are not limited to older patients or patients with generalized periodontal disease. Incidence of fenestration was higher in lower anterior teeth than upper anterior teeth.
5. Prior to the start of any orthodontic treatment, a thorough and comprehensive evaluation of the periodontal bone support must be performed on each individual upper and lower incisor, especially in bimaxillary dentoalveolar protrusive cases. Osteotomy or corticotomy may be considered as adjunct procedures for retraction of anterior teeth.

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