Original Article

A cone-beam computed tomographic evaluation of alveolar bone dimensional changes and the periodontal limits of mandibular incisor advancement in skeletal Class II patients

Kensuke Matsumoto[a]; Scott Sherrill-Mix[b]; Normand Boucher[c]; Nipul Tanna[d]

ABSTRACT

Objectives: To evaluate the presence of dehiscences and changes in alveolar bone height and width in the area of the mandibular central incisors pre- and post-orthodontic treatment.

Materials and Methods: In 60 skeletal Class II patients, cone-beam computed tomographic (CBCT) images were obtained and the patients were divided into four groups based on the presence of dehiscences at pre- and post-orthodontic treatment. The alveolar bone height and width were measured on CBCT in cross section along the long axis of the teeth. Lateral cephalograms were analyzed.

Results: The changes in L1-NB and IMPA appeared to be correlated with vertical bone loss and dehiscence. Alveolar bone height appeared to follow a segmented relationship with these two variables, with changes below a threshold (L1-NB = 0.71 mm, IMPA = 3.02°) having relatively minimal or no effect on bone loss but with changes beyond the threshold correlated with extensive bone loss. Similarly, increases in L1-NB or IMPA correlated with decreases in alveolar bone width (L1-NB: –0.25 mm/mm, IMPA: –0.07 mm/°) and increased the probability of developing dehiscences, with an estimated 50% probability of vertical bone loss at a L1-NB change of 2.00 mm or, equivalently, an IMPA change of 8.02° was estimated.

Conclusions: When treating skeletal Class II patients, the limits of incisor proclination/protraction are less than previously thought. To prevent undesired periodontal outcomes, careful three-dimensional diagnosis is advisable. Furthermore, when excessive protrusion and/or proclination is planned, additional treatment modalities, including orthognathic surgery, tooth extraction, and corticotomy with bone graft, should be considered. (*Angle Orthod.* 2020;90:330–338.)

KEY WORDS: CBCT; Skeletal Class II; Periodontal limits; Bone loss; Dehiscences

INTRODUCTION

Proffit and Ackerman[1] addressed the limitation of tooth movement with a widely accepted diagram described as the "envelope of discrepancy." With orthodontic tooth movement alone, they estimated that the limits of extrusion, retraction, intrusion, and protraction of mandibular incisors were 2, 3, 4, and 5 mm, respectively. These parameters were anecdotally determined by the anatomical boundaries of the alveolar bone width. Strictly focusing on forward tooth movement in animal studies, dehiscences were produced by tipping teeth labially,[2] but bone reformed when the teeth were moved back to their original position.[3] It is important to note that these tooth movements were not necessarily accompanied by attachment loss.

The advent of cone-beam computed tomographic (CBCT) imaging allowed the quantitative assessment of alveolar bone dimensions not previously possible

[a] Instructor, Department of Periodontics and Orthodontics, School of Dental Medicine, University of Pennsylvania, Philadelphia, Pa.

[b] Postdoctoral Fellow, Department of Microbiology, University of Pennsylvania, Philadelphia, Pa.

[c] Clinical Associate Professor, Department of Orthodontics, School of Dental Medicine, University of Pennsylvania, Philadelphia, Pa.

[d] Clinical Associate Professor, Department of Orthodontics, School of Dental Medicine, University of Pennsylvania, Philadelphia, Pa.

Corresponding author: Dr Kensuke Matsumoto, Department of Periodontics and Orthodontics, School of Dental Medicine, University of Pennsylvania, 240 South 40th Street, Evans Building F20, Philadelphia, PA 19104
(e-mail: mkensuke@upenn.edu)

Accepted: December 2019. Submitted: August 2019.
Published Online: February 19, 2020

Table 1. Inclusion and Exclusion Criteria[a]

Inclusion Criteria	Exclusion Criteria
1) CBCT data available between ages of 8 and 20 yrs	1) Severe dental crowding
2) Skeletal Class II (ANB > 3°) with mandibular retrognathia as determined from CBCT-synthesized lateral cephalograms at pre-orthodontic treatment	2) Endodontically treated teeth
3) Angle Class II (full-step or end-to-end) malocclusion at least on one side at pre-orthodontic treatment	3) Restored teeth
4) Angle Class I molar relationships at post-orthodontic treatment	4) Teeth with attachment loss
5) Nonextraction cases	5) Keratinized tissue width less than 2 mm
6) Minimum rotation and crowding on mandibular central incisors	6) Systemically compromised patients
7) Healthy	
8) No history of orthodontic treatment	

[a] CBCT indicates cone-beam computed tomographic.

with two-dimensional imaging. There is a general overestimation of the labiolingual bone width on the lateral cephalograms when compared with physical measurements of the actual specimens, and over 80% of defects identifiable in CT images were not readily visible on the lateral cephalograms.[4]

Dehiscence and fenestration during orthodontic treatment may occur as a result of anatomical and iatrogenic factors.[5,6] To minimize these undesired sequalae, the alveolar bone morphology must be evaluated before orthodontic treatment. While it has been shown that the presence of dehiscence or fenestration[7–10] is not pathognomonic for gingival recession, it is a potential risk.[9,11,12] Therefore, taking this into consideration in a comprehensive treatment plan reduces the risk of future attachment loss, especially when teeth are moved in a labiolingual/buccolingual direction.[13–16]

The purpose of this study was to evaluate the change in alveolar bone dimensions and the presence of dehiscences on mandibular central incisors in skeletal Class II patients between pre- and post-orthodontic treatment in CBCT images as well as any correlation between the change in alveolar bone dimensions and tooth movement based upon cephalometric analysis.

Table 2. Group Distribution Based Upon the Presence of Dehiscences at Pre- and Post-Orthodontic Treatment

Group 1:	There were dehiscences at both pre- and post-orthodontic treatment.
Group 2:	No dehiscences were found at pre-orthodontic treatment and dehiscences developed at post-orthodontic treatment.
Group 3:	No dehiscences were found at both pre- and post-orthodontic treatment.
Group 4:	Dehiscences were found at pre-orthodontic treatment and no dehiscences were detected at post-orthodontic treatment.

MATERIALS AND METHODS

Patients

A total of 60 patients (23 males and 37 females, Caucasian or Asian) with a diagnosis of mandibular retrognathia and Angle Class II malocclusion from a private practice (West Chester, Pa) were enrolled in this retrospective study. All cases were finished between June 2015 and May 2017 and treated with fixed appliances (Andrews2 standard, 0.022-inch slot size, Henry Schein, Melville, NJ) for an average of 28 months by the same orthodontist (NB). Levelling and alignment was achieved from 0.016-inch Nitinol to 0.018 × 0.025-inch stainless-steel arch wires. Proclination of the lower incisors to achieve anterior coupling to camouflage moderate mandibular deficiency was accomplished with short Class II elastics (size: ¼ inch, 4 ounce) on an 0.018-inch stainless-steel arch wire with a reverse curve of Spee. The study was performed with the approval of the institutional review board of the University of Pennsylvania (Protocol 827961). The inclusion and exclusion criteria are listed in Table 1. Based upon the presence of dehiscences pre- and post-orthodontic treatment in CBCT images (Figure 1), patients were divided into four groups (Table 2).

CBCT Evaluation

For each patient, CBCT scans were taken at pre- (T1) and post-orthodontic treatment (T2). Patients were scanned in the natural head position with maximum intercuspation using an iCAT scanner (Imaging Science International, Hatfield, Pa). Images

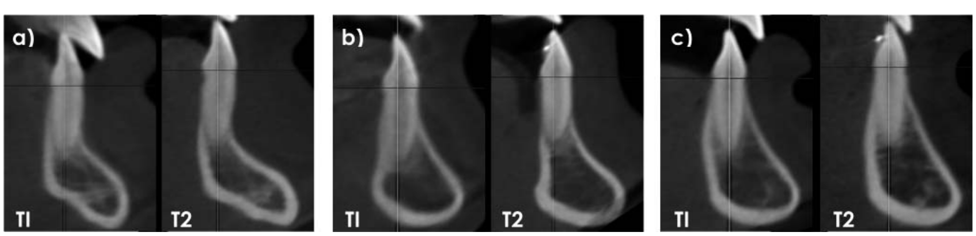

Figure 1. CBCT cross sections. (a) Group 1, (b) Group 2, and (c) Group 3 at T1 and T2.

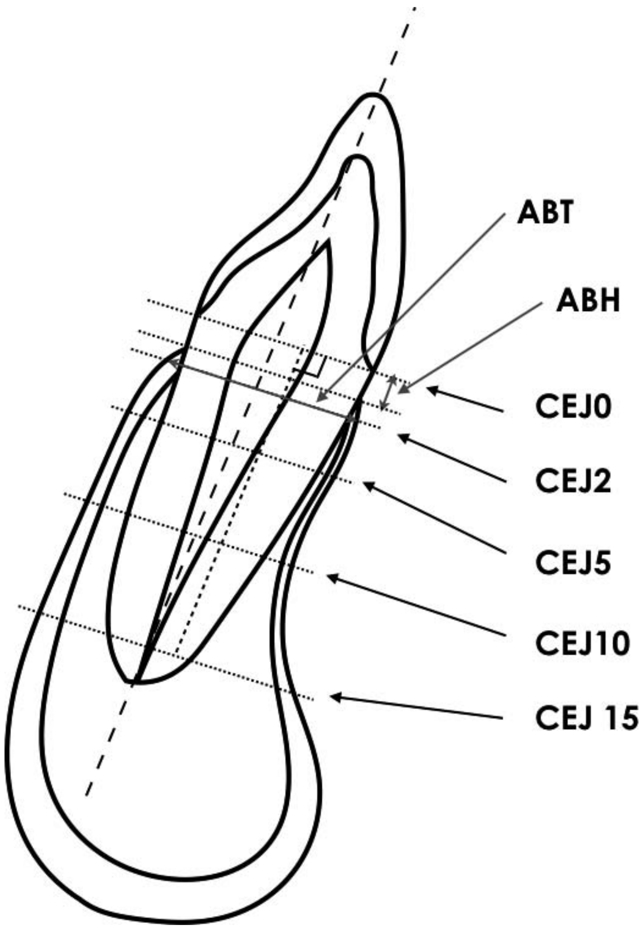

Figure 2. Illustrations of reference points, lines, and measurement variables.

were obtained at a scan time of 4.8 seconds at 0.3 mA, 122 KVp, and with an 0.3-mm voxel size. The digital files (Digital Imaging and Communications in Medicine) of each CBCT scan were exported into Dolphin Imaging software version 11.9.7.20 (Patterson Dental Supply, St Paul, Minn), and three-dimensional (3D) images were reconstructed for evaluations. Cross-sectional slices through the two mandibular central incisors in the 60 patients were generated to show the labial and lingual surfaces of the total 120 central incisors. The slices were generated at the putative midline of the long axis labiolingually on each tooth and reconstructed with 2.0-mm slice thickness.

Measurements

The following measurements on the 60 sets of CBCT-synthesized lateral cephalogram were analyzed at T1 and T2: (1) SNA (°), (2) SNB (°), (3) ANB (°), (4) MP-SN (°), (5) FMA (°), (6) L1-NB (mm), and (7) IMPA (°). One operator traced and measured the entire sample of cephalometric analyses.

The alveolar bone thicknesses (ABT) between the surface of the labial and lingual cortical plates at the level of 2 (CEJ2), 5 (CEJ5), 10 (CEJ10), and 15 (CEJ15) mm from the cementoenamel junction (CEJ) were measured on CBCT images in cross section along the long axis of the central incisors. The presence of dehiscence and the change in alveolar bone height (ABH) were also evaluated at both T1 and T2 (Figure 2). Each root was viewed in axial and cross-sectional slices at the buccal and lingual surfaces. A dehiscence was identified when there was no cortical bone on the labial surface in at least three sagittal views and the ABH was more than 2 mm from the CEJ.[17] ABH was measured from the CEJ to the most coronal part of labial alveolar bone crest (ABC) through the tooth long axis. A CEJ-to-ABC measurement of less than 2 mm was deemed normal, based on previous studies.[6,17,18] Alveolar bone loss was defined as sites showing a reduction of ABH over the course of treatment and where the CEJ-to-ABC distance was greater than 2 mm after treatment. All measurements were determined on both central incisors, and the mean of the two was used for further analyses.

Two examiners were calibrated for the measurements of alveolar bone on the CBCT images and synthesized lateral cephalograms using the same computer under the same conditions. To evaluate the reliability of the linear measurements, 10 patients were randomly selected from the total sample. Intraoperator reliability was determined twice at an interval of 2 weeks, and interoperator reliability was determined between two operators (Table 3). For intraoperator reliability, the mean absolute differences in ABT estimates were 0.24 mm with a Pearson correlation of $r = 0.93$ and 0.44 mm with a correlation of $r = 0.91$ for ABH. Between operators, the mean absolute difference was 0.29 mm, with $r = 0.92$, for the thickness, and 0.28 mm, with $r = 0.95$, for the height. The high

Table 3. Intra- and Interoperator Reliability as Demonstrated by Mean Difference, Mean Absolute Difference, and Pearson Correlation[a]

	Intraoperator				Interoperator			
	ABT	95% CI	ABH	95% CI	ABT	95% CI	ABH	95% CI
Mean difference, mm	0.00	−0.13 to 0.12	−0.08	−0.33 to 0.17	−0.17	−0.40 to 0.06	−0.02	−0.26 to 0.22
Mean absolute difference, mm	0.24	0.18–0.29	0.28	0.13–0.43	0.29	0.15–0.43	0.44	0.34–0.54
Pearson correlation	0.93	0.82–0.97	0.95	0.80–0.99	0.92	0.68–0.98	0.91	0.78–0.96

[a] ABT indicates alveolar bone thickness; CI, confidence interval; and ABH, alveolar bone height.

Table 4. Age of Subjects[a]

Age, y	Male (N = 19) Mean	Male SD	Female (N = 29) Mean	Female SD	Total (N = 48) Mean	Total SD	*P* Value	Significance
T1	11.5	1.90	11.0	1.35	11.2	1.59	.335	N.S.
T2	14.8	1.54	14.2	0.87	14.5	1.20	.134	N.S.
T2–T1	3.3	0.95	3.2	1.29	3.2	1.16	.738	N.S.

[a] SD indicates standard deviation; N.S. indicates Not significant; T1, pre-orthodontic treatment; and T2, post-orthodontic treatment.

correlation between and within operators suggested that these measurements were replicable and robust.

Statistics

Paired *t*-tests were used to evaluate differences between pre- and post-treatment measurements of ABT, ABH, and cephalometric analysis, and two sample *t*-tests were used to compare male and female measurements. Additionally, segmented regression, linear regression, and logistic regression analyses were applied to assess associations between tooth movements and the risk of developing dehiscences. Statistical significance was set at $P < .05$.

RESULTS

Eleven patients (four males and seven females) were excluded from the analysis because of the lack of adequate quality for evaluation of the CBCT images. The mean ages of patients were 11.23 (standard deviation [SD] = 1.59) years at T1 and 14.48 (SD = 1.20) years at T2 in Table 4. There were no significant differences in age between male and female groups ($P > .05$). The results of the lateral cephalometric measurements listed in Table 5 showed that no skeletal or dental variations were found between males and females ($P > .05$) except for the MP-SN change ($P < .05$).

There was no statistically significant difference between males and females regarding the ABT at each level of the CEJ at T1 and T2. Comparisons between males and females for ABT, CEJ5, and CEJ15 were slightly below $P = .05$, but this significance would not survive correction for multiple comparisons (Table 6). The prevalence of dehiscences is shown in Table 7; 31.6% of teeth in males and 24.1% of teeth in females had dehiscences at T1. The incidence of dehiscences increased to 57.9% in males and to 44.8% in females at T2. There was no significant association between sex and dehiscence frequency at either time point (both $P > .05$; Fisher's exact test).

The patients were divided into four groups based on the presence of dehiscence (Table 2), and each group was compared with the others (Table 8). No patients

Table 5. Cephalometric Analysis of Comparisons Between Males and Females[a]

Measurement		Male (N = 19) Mean	Male SD	Female (N = 29) Mean	Female SD	Total (N = 48) Mean	Total SD	*P* Value	Significance
SNA, °	T1	81.85	3.61	81.01	2.91	81.34	3.20	.399	N.S.
	T2	82.74	3.49	81.59	0.58	82.04	3.17	.242	N.S.
	T2–T1	0.88	1.02	0.58	0.67	0.70	0.83	.259	N.S.
SNB, °	T1	76.98	2.92	76.46	2.47	76.67	2.64	.529	N.S.
	T2	78.23	2.53	76.87	2.88	77.41	2.80	.091	N.S.
	T2–T1	1.25	1.38	0.40	1.51	0.74	1.50	.052	N.S.
ANB, °	T1	4.93	1.62	4.57	1.25	4.71	1.40	.413	N.S.
	T2	4.51	2.01	4.72	1.85	4.64	1.90	.711	N.S.
	T2–T1	−0.37	1.15	0.18	1.41	−0.04	1.32	.149	N.S.
MP-SN, °	T1	31.99	4.73	32.24	5.00	32.14	4.84	.864	N.S.
	T2	30.36	5.36	32.17	6.28	31.45	5.94	.291	N.S.
	T2–T1	−1.64	1.53	−0.08	3.09	−0.70	2.68	.026	*
FMA, °	T1	24.23	4.92	23.97	4.37	24.07	4.55	.849	N.S.
	T2	22.74	5.53	23.81	5.40	23.39	5.42	.512	N.S.
	T2–T1	−1.49	1.39	−0.20	3.08	−0.71	2.61	.055	N.S.
L1-NB, mm	T1	3.73	2.15	3.62	1.39	3.66	1.71	.844	N.S.
	T2	4.81	2.77	4.81	2.00	4.81	2.30	.996	N.S.
	T2–T1	1.08	1.96	1.19	1.59	1.14	1.72	.843	N.S.
IMPA, °	T1	90.92	5.49	91.19	5.91	91.08	5.69	.872	N.S.
	T2	96.44	5.10	95.54	6.84	95.90	6.17	.606	N.S.
	T2–T1	5.53	5.34	4.38	4.39	4.83	4.77	.441	N.S.

[a] SD indicates standard deviation; N.S. indicates Not significant; T1, pre-orthodontic treatment; and T2, post-orthodontic treatment.
* $P < .05$.

Table 6. The Changes of Alveolar Bone Thickness at Each Level of the Tooth and Alveolar Bone Height (ABH)[a]

Alveolar Bone Thickness		Male (N = 19)		Female (N = 29)		Total (N = 48)			
		Mean	SD	Mean	SD	Mean	SD	*P* Value	Significance
CEJ2, mm	T1	6.07	0.71	5.97	0.48	6.01	0.58	.6049	N.S.
	T2	5.41	0.64	5.43	0.74	5.42	0.70	.9125	N.S.
	T2–T1	−0.66	0.60	−0.54	0.52	−0.59	0.55	.4803	N.S.
CEJ5, mm	T1	6.79	0.70	6.67	0.78	6.72	0.75	.5847	N.S.
	T2	5.81	0.76	5.99	0.89	5.92	0.84	.4575	N.S.
	T2–T1	−1.02	0.55	−0.68	0.55	−0.82	0.57	.0399	*
CEJ10, mm	T1	8.74	1.33	8.87	1.95	8.81	1.71	.7867	N.S.
	T2	7.43	1.75	8.11	2.48	7.84	2.22	.2776	N.S.
	T2–T1	−1.30	0.88	−0.76	0.99	−0.98	0.98	.0542	N.S.
CEJ15, mm	T1	11.63	1.86	12.95	2.22	11.45	2.07	.6180	N.S.
	T2	10.26	1.94	12.90	3.16	10.68	2.74	.3523	N.S.
	T2–T1	−1.37	1.63	−0.05	1.35	−0.77	1.53	.0349	*
ABH, mm	T1	−2.18	1.07	−2.34	1.58	−2.28	1.39	.5452	N.S.
	T2	−3.76	2.12	−3.66	2.45	−3.70	2.32	.8304	N.S.
	T2–T1	−1.58	2.19	−1.32	1.90	−1.42	2.02	.5436	N.S.

[a] SD indicates standard deviation; N.S. indicates Not significant; T1, pre-orthodontic treatment; T2, post-orthodontic treatment; and CEJ, cementoenamel junction.

* $P < .05$.

classified into group 4 were identified. In comparing groups 2 and 3, statistically significant alveolar bone reduction occurred at CEJ2 (–1.47 vs –0.30 mm, $P < .001$) and at CEJ5 (–1.34 vs –0.70 mm, $P < .05$) at T2. Group 2 exhibited the highest percentage of alveolar bone loss at T2 (–23.7% at CEJ2, –19.9% at CEJ5). By contrast, there were no significant differences at CEJ10 and CEJ15 between the groups. With regard to the ABH, there was no difference between groups 2 and 3 at T1, while group 2 decreased 4.5 mm more than group 3 at T2 ($P < .001$). The parameters (L1-NB and IMPA) on the cephalometrics differed significantly between the groups. In group 2, the change of L1-NB (mean: 3.1 mm) was significantly greater compared with group 1 (mean: 0.9 mm) and group 3 (mean: 0.4 mm) ($P < .01$). There was a statistically significant increase of IMPA (9.73°) in group 2 compared with groups 1 (3.74°) and 3 (3.15°) (both $P < .001$).

Based on the data, the relationship between dehiscence and tooth movement appeared to have a threshold point beyond which tooth movement rapidly increased bone loss (Davie's test: L1-NB, $P = .005$; IMPA, $P = .035$). The model estimated this critical threshold as an L1-NB change of 0.71 mm (95% confidence interval [CI]: –0.15 to 1.58 mm; Figure 3a) or an IMPA change of 3.02° (95% CI: –0.44 to 6.48°; Figure 3b). Tooth movements beyond this threshold were estimated to result in a 1.49-mm (95% CI: 1.10–1.87 mm) loss in ABH for each 1-mm L1-NB change or a 0.48-mm (95% CI: 0.29–0.67 mm) loss for each 1° increase in IMPA. There did not appear to be a significant threshold point in the relationship between CEJ2 and these variables (Davie's test; L1-NB, $P = .33$; IMPA, $P = .18$). At CEJ2, a simple linear relationship between these two variables would predict, on average, that each 1-mm change in L1-NB would decrease 0.25-mm ABT (95% CI: 0.17–0.34 mm; Figure 4a) or each 1° change in IMPA would decrease 0.07-mm ABT (95% CI: 0.04–0.11 mm; Figure 4b).

Logistic regressions were used to estimate the probability of developing dehiscences based on the change in L1-NB (Figure 5a) or IMPA (Figure 5b). Each 1-mm change in L1-NB was predicted to increase the odds of developing dehiscence by 6.86-fold (95% CI: 1.61–29.2-fold), while a 1° change in IMPA was predicted to increase the odds by 1.73-fold (95% CI: 1.19–2.51-fold). This translates into an estimated 50% probability of vertical bone loss at an L1-NB change 2.00 mm or, equivalently, an IMPA change of 8.02°.

Table 7. The Prevalence of Dehiscences in the Mandibular Central Incisors[a]

	Male (n = 38)				Female (n = 58)				Total (n = 96)			
	T1		T2		T1		T2		T1		T2	
Dehiscence	n	%	n	%	n	%	n	%	n	%	n	%
Present	12	31.6	22	57.9	14	24.1	26	44.8	26	27.1	48	50.0
Absent	26	68.4	16	42.1	44	75.9	32	55.2	70	72.9	48	50.0

[a] T1 indicates pre-orthodontic treatment; T2, post-orthodontic treatment.

Table 8. Cephalometric and Cone-Beam Computed Tomographic (CBCT) Characteristics, Comparing Between the Groups (*t*-Tests)[a]

Group		Group 1: N = 13 Mean	Group 1: SD	Group 2: N = 11 Mean	Group 2: SD	Group 3: N = 24 Mean	Group 3: SD	G1 vs G2 *P* Value	G2 vs G3 *P* Value	G1 vs G3 *P* Value
Age, y	T1	11.62	0.87	10.91	2.70	11.17	1.20	.422	.767	.202
	T2	14.46	0.97	14.73	1.90	14.38	0.92	.681	.570	.794
	T2–T1	2.85	0.80	3.82	1.47	3.21	1.10	.069	.239	.260
CEJ2, mm	T1	5.75	0.60	6.22	0.61	6.06	0.52	.076	.461	.138
	T2	5.38	0.65	4.75	0.58	5.76	0.54	<.05*	<.001**	.091
	T2–T1	−0.37	0.21	−1.47	0.33	−0.30	0.23	<.001**	<.001**	.372
CEJ5, mm	T1	6.60	0.65	6.69	0.78	6.80	0.80	.753	.708	.408
	T2	6.01	0.67	5.35	0.78	6.14	0.85	<.05*	<.05*	.629
	T2–T1	−0.58	0.37	−1.34	0.66	−0.70	0.48	<.001**	<.05*	.424
CEJ10, mm	T1	8.76	1.06	8.36	1.30	9.05	2.13	.426	.249	.585
	T2	7.93	1.93	7.01	1.75	8.17	2.52	.231	.127	.755
	T2–T1	−0.83	1.24	−1.35	1.03	−0.88	0.78	.266	.194	.887
CEJ15, mm	T1	10.90	1.31	11.19	1.75	11.86	2.48	.654	.364	.130
	T2	10.77	2.34	9.95	2.62	10.96	3.03	.437	.328	.831
	T2–T1	−0.13	1.45	−1.24	1.76	−0.91	1.41	.115	.592	.132
ABH, mm	T1	4.24	1.32	1.60	0.21	1.51	0.22	<.001**	.314	<.001**
	T2	5.02	1.80	6.35	1.54	1.76	0.16	.063	<.001**	<.001**
	T2–T1	0.78	0.78	4.75	1.53	0.25	0.14	<.001	<.001**	<.05*
SNA, °	T1	82.33	3.14	80.77	1.97	81.07	3.64	.155	.759	.279
	T2	83.05	3.24	81.62	2.17	81.69	3.50	.212	.940	.249
	T2–T1	0.72	0.87	0.85	1.24	0.62	0.57	.773	.583	.740
SNB, °	T1	77.21	2.47	75.80	1.77	76.77	3.03	.120	.244	.640
	T2	77.70	2.44	76.34	2.34	77.74	3.13	.178	.153	.968
	T2–T1	0.49	1.51	0.54	1.78	0.97	1.40	.949	.489	.358
ANB, °	T1	5.14	1.26	5.07	1.77	4.32	1.22	.919	.220	.068
	T2	5.35	1.71	5.28	2.29	3.95	1.62	.940	.104	.423
	T2–T1	0.22	1.22	0.31	1.38	−0.34	1.34	.874	.206	.335
MP-SN, °	T1	31.48	3.66	33.77	3.69	31.76	5.78	.142	.224	.857
	T2	30.28	4.33	34.34	4.46	30.76	6.97	<.05*	.078	.799
	T2–T1	−1.19	1.89	0.55	3.08	−1.00	2.78	.122	.173	.801
FMA, °	T1	23.60	4.02	25.61	4.35	23.62	4.91	.257	.241	.989
	T2	22.28	5.18	26.35	4.84	22.63	5.51	.060	.056	.850
	T2–T1	−1.32	2.20	0.62	2.84	−0.99	2.60	.081	.128	.688
L1-NB, mm	T1	3.79	1.96	3.77	1.45	3.55	1.74	.978	.691	.708
	T2	4.65	2.27	6.89	1.82	3.94	1.96	<.05*	<.001**	.355
	T2–T1	0.85	1.62	3.12	1.46	0.40	1.13	<.001**	<.001**	.375
IMPA, °	T1	91.11	4.07	89.50	6.34	91.79	6.20	.479	.331	.691
	T2	94.85	4.39	99.23	5.59	94.94	6.87	<.05*	.062	.963
	T2–T1	3.75	4.36	9.78	2.83	3.15	4.20	<.001**	<.001**	.693

[a] SD indicates standard deviation; T1, pre-orthodontic treatment; T2, post-orthodontic treatment; CEJ, cementoenamel junction; and ABH, alveolar bone height.

* $P < .05$; ** $P < .001$.

DISCUSSION

The etiology of dehiscence and fenestration during orthodontic treatment is multifactorial and includes, but is not limited to, the direction of tooth movement, the magnitude of orthodontic forces, the amount of tooth movement, the dimensions of alveolar bone, the position of the roots, and the anatomic integrity of periodontal tissues.[5,6] Anatomically, the alveolar bone becomes thinner from the posterior to the anterior region in the mandible.[19] Therefore, in the area of the mandibular symphysis, the direction and amount of tooth movement can easily violate the biologic limits of the alveolar process.

The advent of CBCT imaging provides an excellent diagnostic modality with which to critically evaluate this area. Timock et al.[20] compared CBCT with direct measurements on cadavers for buccal bone height and thickness and found strong agreement. Mean absolute errors between CBCT and direct measurements of buccal bone height and thickness were small (0.30 and 0.13 mm, respectively) and showed no statistically significant differences or bias to underestimate or overestimate. Interoperator and intraoperator reliabilities had great agreement for CBCT measurements of buccal bone height (>0.97) and thickness (0.90). Sun et al.[21] reported that the sensitivity and specificity rates of CBCT for dehiscences were over

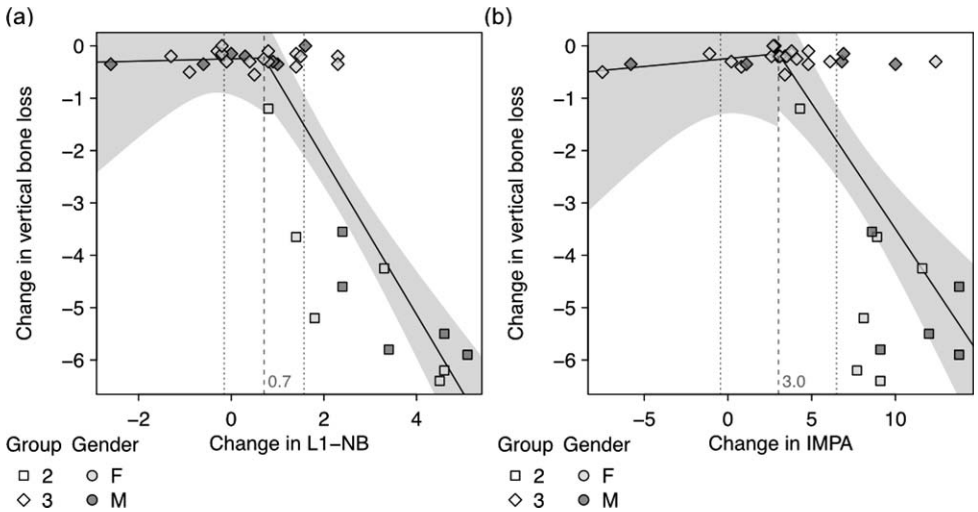

Figure 3. Segmented regression analyses between the ABH change and (a) L1-NB and (b) IMPA changes.

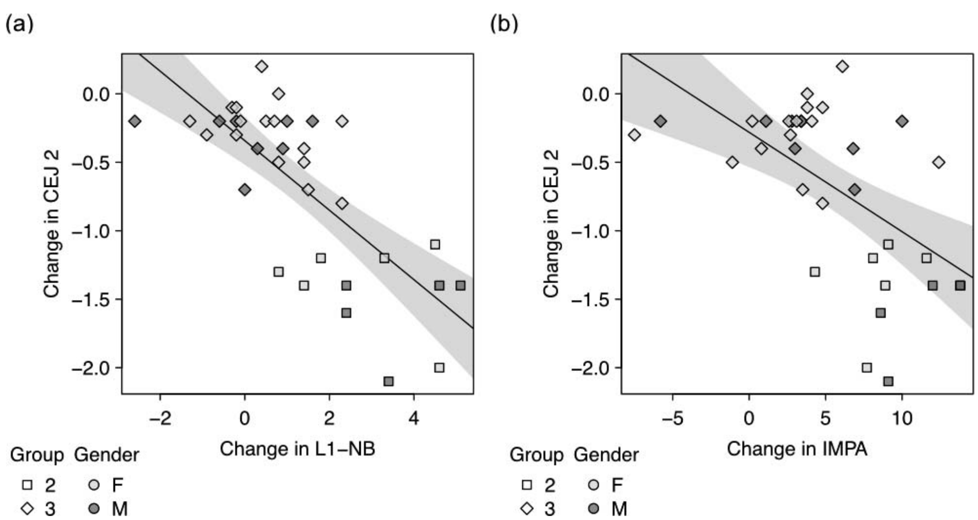

Figure 4. Linear regression analyses between the ABT change in CEJ2 and (a) L1-NB and (b) IMPA changes.

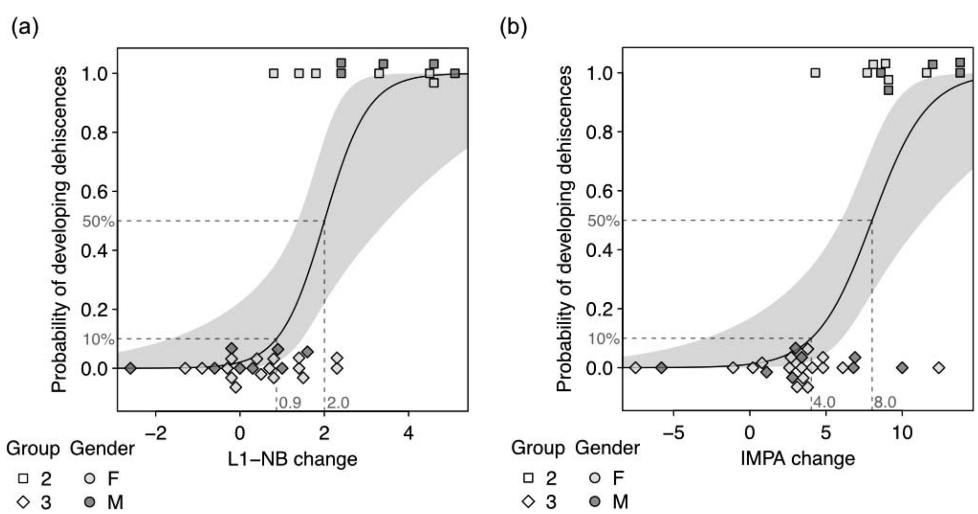

Figure 5. Logistic regression analyses to estimate the probability of developing dehiscences on (a) L1-NB and (b) IMPA.

0.7 and concluded that the CBCT method might overestimate the actual measurements. The 0.3-mm voxel size was selected based on the balance of the amount of radiation exposure and clinical relevance. While the produced results of ABT and ABH would be accurate, the sensitivity might not be as high as the specificity.

The current study results showed that the presence of dehiscences in the mandibular central incisors increased from 27.1% to 50.0% after orthodontic treatment. Previous studies[7,8,22] reported that the presence of dehiscences with different facial types, skeletal types, and vertical growth patterns ranged from 24.33% to 27.11%; these values are consistent with those from the current study.

In untreated subjects, the impact of growth on mandibular central incisors is minimal, and teeth tend to upright.[23–25] In comparing this study's results with these studies, skeletal changes were similar but IMPA, and L1-NB increased extensively after the treatment. The 22.9% increase in dehiscences in the central incisors after tooth movement was not due to growth alone but rather to the treatment modality of the Class II patients.

Patients lost a significant amount of ABT over the course of the study. Approximately 10% of ABT at CEJ2 and CEJ5 was lost during the treatment (Table 6). The amount of alveolar bone loss was greater at the cervical than at the apical area (Table 8). This may be attributed to protrusion and proclination. The inclusion criteria were patients between the ages of 8 and 20 years (Table 1). However, Jäger et al.[26] reported that a significantly greater dehiscence depth with increased vertical bone loss occurred in patients older than 30 years. The age differences may be a factor, resulting in even higher risks in adults. The large range in age in the current study justifies further investigation to determine the effect of age on susceptibility to dehiscence. Additionally, considering the thin anatomy of the labial plate, it was decided to not measure individual labial and lingual bone widths.

Animal studies[2,3] showed histologic evidence of alveolar crestal bone loss when the tooth moved labially, but attachment loss did not occur. Additionally, none of the studies[2,3,27] indicated that the cortical plate was reestablished. It can be concluded that bone formation does not occur around newly developed dehiscences after tooth movement, even though the force application is terminated, and the teeth are retained in their facially displaced position.[3] In this study, T2 scans were taken at least 3 to 6 months[28] after tooth movement.

The most striking finding in the present study was the strong correlation between dehiscence and tooth movement. ABH appeared to follow a segmented relationship with L1-NB or IMPA, with changes below a threshold having relatively little effect on bone loss but with changes beyond the threshold correlated with bone loss. Similarly, increases in L1-NB or IMPA correlated with decreases in ABT and increased probability of developing dehiscences. In a study[15] that focused on developing recession rather than dehiscence based on IMPA significantly more recessions developed during orthodontic treatment and a 3-year postoperative period in the patients with excessive proclination. In the current study, a significant relationship was also observed between both L1-NB and IMPA and the development of dehiscences. Exact limits will depend on the direction, magnitude, and amount of tooth movement, including the alveolar bone dimension and the position of the root. Based on the patients in this study, if a threshold at a 50% probability of developing dehiscence was set, then a threshold for L1-NB would be limited to 2.00 mm and, equivalently, for IMPA, a threshold of 8.02°. However, it appears that bone loss may begin to increase even earlier, and, thus, these 50% thresholds would be predicted to decrease ABH by about 1.92 mm and ABT by 0.50 mm, on average. For a more conservative threshold of a 10% probability of developing dehiscences with little predicted bone loss, thresholds of L1-NB movement of less than 0.86 mm or an IMPA change of less than 4° could be used.

CONCLUSIONS

- When treating skeletal Class II mandibular retrognathic patients, the limits of mandibular central incisor forward movement might be less than previously thought when considering the adverse effect on the alveolar bone. In order to avoid the undesired periodontal outcomes during and/or after orthodontic treatment, careful 3D diagnosis is essential.
- Furthermore, when excessive protrusion/proclination is planned, additional treatment modalities, such as orthognathic surgery, tooth extraction, and partial corticotomy with bone graft, should be considered.

REFERENCES

1. Proffit WR, Ackerman JL. Diagnosis and treatment planning. In: Graber TM, Swain BF, eds. *Current Orthodontic Concepts and Techniques,* 1st ed. St Louis, Mo; Mosby Inc; 1982:3–100.
2. Wennström JL, Lindhe J, Sinclair F, Thilander B. Some periodontal tissue reactions to orthodontic tooth movement in monkeys. *J Clin Periodontol*. 1987;14:121–129.
3. Karring T, Nyman S, Thilander B, Magnusson I. Bone regeneration in orthodontically produced alveolar bone dehiscences. *J Periodontal Res*. 1982;17:309–315.

4. Fuhrmann R. Three-dimensional interpretation of labiolingual bone width of the lower incisors. *J Orofac Orthop*. 1996;57:168–185.
5. Wennström JL. Mucogingival considerations in orthodontic treatment. *Semin Orthod*. 1996;2:46–54.
6. Wehrbein H, Bauer W, Diedrich P. Mandibular incisors, alveolar bone and symphysis after orthodontic treatment: a retrospective study. *Am J Orthod Dentofacial Orthop*. 1996;110:239–246.
7. Evangelista K, Vasconcelos KF, Bumann A, Hirsch E, Nitka M, Silva MAG. Dehiscence and fenestration in patients with Class I and Class II Division 1 malocclusion assessed with cone-beam computed tomography. *Am J Orthod Dentofacial Orthop*. 2010;138:133.e1–133.e7.
8. Yagci A, Veli I, Uysal T, Ucar FI, Ozer T, Enhos S. Dehiscence and fenestration in skeletal Class I, II, and III malocclusions assessed with cone-beam computed tomography. *Angle Orthod*. 2012;82:67–74.
9. Nahm KY, Kang JH, Moon SC, et al. Alveolar bone loss around incisors in Class I bidentoalveolar protrusion patients: a retrospective three-dimensional cone beam CT study. *Dentomaxillofac Radiol*. 2012;41:481–488.
10. Gracco A, Luca L, Bongiorno MC, Siciliani G. Computed tomography evaluation of mandibular incisor bony support in untreated patients. *Am J Orthod Dentofacial Orthop*. 2010;138:179–187.
11. Artun J, Krogstad O. Periodontal status of mandibular incisors following excessive proclination. A study in adults with surgically treated mandibular prognathism. *Am J Orthod Dentofacial Orthop*. 1987;91:225–232.
12. Joss-Vassalli I, Grebenstein C, Topouzelis N, Sculean A, Katsaros C. Orthodontic therapy and gingival recession: a systematic review. *Orthod Craniofac Res*. 2010;13:127–141.
13. Renkema AM, Fudalej PS, Renkema AA, Abbas F, Bronkhorst E, Katsaros C. Gingival labial recessions in orthodontically treated and untreated individuals: a case-control study. *J Clin Periodontol*. 2013;40:631–637.
14. Lund H, Gröndahl K, Gröndahl HG. Cone beam computed tomography evaluations of marginal alveolar bone before and after orthodontic treatment combined with premolar extractions. *Eur J Oral Sci*. 2012;120:201–211.
15. Renkema AM, Fudalej PS, Renkema A, Kiekens R, Katsaros C. Development of labial gingival recessions in orthodontically treated patients. *Am J Orthod Dentofacial Orthop*. 2013;143:206–212.
16. Richman C. Is gingival recession a consequence of an orthodontic tooth size and/or tooth position discrepancy? "A paradigm shift." *Compend Contin Educ Dent*. 2011;32:e73–e79.
17. Persson RE, Hollender LG, Laurell L, Persson GR. Horizontal alveolar bone loss and vertical bone defects in an adult patient population. *J Periodontol*. 1998;69:348–356.
18. Lupi JE, Handelman CS, Sadowsky C. Prevalence and severity of apical root resorption and alveolar bone loss in orthodontically treated adults. *Am J Orthod Dentofacial Orthop*. 1996;109:28–37.
19. Swasty D, Lee JS, Huang JC, et al. Anthropometric analysis of the human mandibular cortical bone as assessed by cone-beam computed tomography. *J Oral Maxillofac Surg*. 2009;67:491–500.
20. Timock AM, Cook V, McDonald T, et al. Accuracy and reliability of buccal bone height and thickness measurements from cone-beam computed tomography imaging. *Am J Orthod Dentofacial Orthop*. 2011;140:734–744.
21. Sun L, Zhang L, Shen G, Wang B, Fang B. Accuracy of cone-beam computed tomography in detecting alveolar bone dehiscences and fenestrations. *Am J Orthod Dentofacial Orthop*. 2015;147:313–323.
22. Enhos S, Uysal T, Yagci A, et al. Dehiscence and fenestration in patients with different vertical growth patterns assessed with cone-beam computed tomography. *Angle Orthod*. 2012;82:868–874.
23. Chung CH, Wong WW. Craniofacial growth in untreated skeletal Class II subjects: a longitudinal study. *Am J Orthod Dentofacial Orthop*. 2002;122:619–626.
24. Stahl F, Baccetti T, Franchi L, McNamara JA Jr. Longitudinal growth changes in untreated subjects with Class II Division 1 malocclusion. *Am J Orthod Dentofacial Orthop*. 2008;134:125–137.
25. Baccetti T, Stahl F, McNamara JA Jr. Dentofacial growth changes in subjects with untreated Class II malocclusion from late puberty through young adulthood. *Am J Orthod Dentofacial Orthop*. 2009;135:148–154.
26. Jäger F, Mah JK, Bumann A. Peridental bone changes after orthodontic tooth movement with fixed appliances: a cone-beam computed tomographic study. *Angle Orthod*. 2017;87:672–680.
27. Steiner GG, Pearson JK, Ainamo J. Changes of the marginal periodontium as a result of labial tooth movement in monkeys. *J Periodontol*. 1981;52:314–320.
28. Sarikaya S, Haydar B, Ciğer S, Ariyürek M. Changes in alveolar bone thickness due to retraction of anterior teeth. *Am J Orthod Dentofacial Orthop*. 2002;122:15–26.