Original Article

The effect of root and bone visualization on perceptions of the quality of orthodontic treatment simulations

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ABSTRACT

Objective: To evaluate the effect of root and bone visibility on orthodontists' perceptions of the quality of treatment simulations.

Material and Methods: An online survey was used to present orthodontists with setups generated for 10 patients in two different types of view: with and without bone and roots as modeled from a cone-beam computed tomography (CBCT) scan. The orthodontists were asked to rate the quality of the setups from poor to ideal on a 100-point visual analog scale and, if applicable, to identify features of concern that led them to giving a setup a less-than-ideal rating.

Results: The quality ratings were significantly lower when roots and bone were visible in the setups ($P < .0001$). Buccolingual inclination and periodontal concerns were selected significantly more often as reasons for a less-than-ideal rating when roots and bone were shown, whereas occlusal relationship, overjet, occlusal contacts, and arch form were selected significantly more often as reasons for a less-than-ideal rating when roots and bone were not shown. The odds of selecting periodontal concerns as a reason for a less-than-ideal setup rating were 331 times greater when roots and bones were visible than when they were not.

Conclusions: Additional diagnostic information derived from CBCT scans affects orthodontists' perceptions of the overall case quality, which may influence their treatment-planning decisions. (*Angle Orthod.* 2017;87:384–390)

KEY WORDS: 3-D imaging; CBCT; Setup; Case quality

INTRODUCTION

With the increasing use of cone-beam computed tomography (CBCT), orthodontists have more diagnostic information than ever, including data regarding the alveolar bone coverage of roots.[1] Currently, this is not reflected in the case evaluation system used by the American Board of Orthodontics (ABO), which places a major emphasis on the final occlusion and draws its scoring criteria from dental models and panoramic radiographs.[2] However, with the expanded information from CBCT, orthodontists must balance placing a tooth within the alveolar bone with creating an ideal occlusion. While some orthodontists may choose to compromise the quality of the final occlusion in favor of facial bone coverage, others may utilize the additional information to improve tooth positioning based on the unique perspective on tooth angulation and inclination afforded.

One new application of technology that uses CBCT data is the SureSmile system (OraMetrix, Richardson, Tex). This all-digital system allows orthodontists to create three-dimensional (3-D) setups from digital models and CBCT scans.[3] Treatment can be simulated with high-resolution visual information about crowns, roots, and alveolar bone, shown either separately or simultaneously. While construction of orthodontic setups blending digital models and CBCT has also been described using other types of software,[4,5] the SureSmile system is unique in that it allows fabrication of robot-bent archwires,[6] which have been shown to produce treatment outcomes similar to those predicted in the setup.[7,8]

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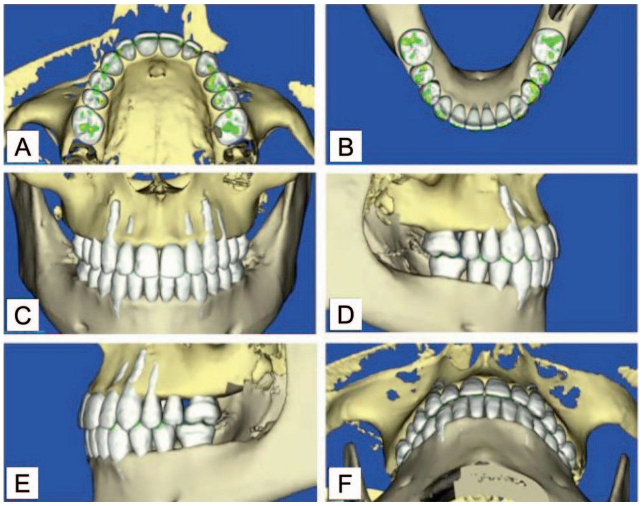

Figure 1. Examples of images generated for a full-view setup: (A) upper occlusal view, (B) lower occlusal view, (C) frontal view, (D) right lateral view, (E) left lateral view, and (F) overjet.

Although current digital simulations do not allow measurement of facial bone thickness, they may provide a warning sign when large alveolar fenestrations or dehiscences appear after simulated tooth movements. Orthodontists therefore have the ability to alter their occlusal treatment goals to help reduce the risk of adverse periodontal outcomes.[9,10] However, whether root and bone visualization in the setups influences tooth positioning decisions remains unclear. A better understanding of its potential advantages is important for orthodontists to fully consider the risks and benefits of CBCT with its associated ionizing radiation,[11,12] since digital setups can also be created from intraoral scans, which provide visualization of the crowns only. For this reason, this study investigated the effect of root and bone visibility on orthodontists' perceptions of ideal tooth position.

MATERIALS AND METHODS

The research protocol was approved by the Institutional Review Board at the University of Minnesota (Study No. 1407E52683). Potential subjects were all active members of the American Association of Orthodontists (AAO) listed in the AAO's Online Member Directory with at least one office location within the United States. Subjects were excluded if they listed no e-mail address or were a student or retired member. The subjects were contacted by e-mail with a link to a customized survey hosted by an online survey platform (Qualtrics, Provo, Utah). The subjects could complete the survey anonymously on their computer or mobile device using the browser of their choice. No time restriction was imposed and subjects could save their responses and return to the survey if they chose not to complete it in one session. Two reminder e-mails were sent to those who did not opt out from future communication.

Following a brief introduction, the subjects were asked whether they felt comfortable evaluating CBCT scans for orthodontic treatment planning purposes. Any subjects who identified themselves as not comfortable evaluating CBCTs were redirected from the survey. A consent information form was presented as a downloadable PDF file to those who passed the screening process. The subjects were able to proceed only after confirming that they had read the form and provided consent.

Setups were generated for 10 patients who met the inclusion criteria of Class I molar occlusion and presence of all permanent teeth with the exception of third molars. All setups were generated using SureSmile software from existing CBCT scans taken on an i-CAT Next Generation (Imaging Sciences International, Hatfield, Pa) at 120 kV and 37.07 mAs, with a pulsed scan time of 26.9 seconds, a voxel size of 0.2 mm^3, and using a SureSmile filter. Existing CBCT scans were chosen to ensure that patients were not exposed to radiation solely for study purposes. All identifying features and orthodontic attachments were digitally removed. Due to irregularities in the occlusion at the second molars, these teeth were removed from the setups as well.

For each of the 10 setups, six images and one video clip were generated (Image capture software: Snipping Tool, Microsoft, Redmond, Wash; Video capture software: Debut Pro Edition, NCH Software, Greenwood Village, Colo). The images showed upper and lower occlusal views, frontal view, right and left lateral views, and overjet. The videos showed the setup being rotated around a vertical axis for approximately 15 seconds followed by each arch being shown individually and moving from a frontal view to an occlusal view for approximately 10 seconds per arch. The subjects were able to pause, resume, and replay the videos.

In the survey, the setups were presented in two different types of view. One type of view, named "full view," showed the bone and roots as modeled by the SureSmile software from a CBCT scan (Figure 1). The other type of view, named "restricted view," hid both the bone and roots, showing only the crowns and truncated roots (Figure 2). This view simulated the appearance of setups generated from direct intraoral scans. Two full-view setups and two restricted-view setups were randomly selected and shown twice in the survey to assess intrarater agreement (Figure 3). The order of the setups was randomized for each type of view, with the condition that setups shown twice to assess intrarater agreement were separated from each other by at least two other setups. The following legend

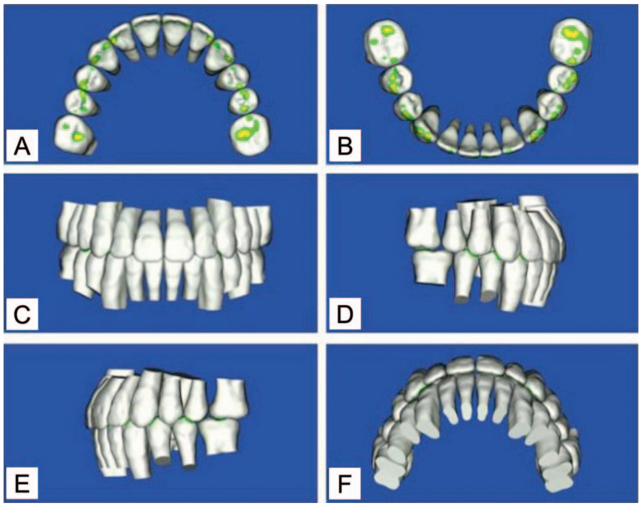

Figure 2. Examples of images generated for a restricted-view setup, without roots and bone: (A) upper occlusal view, (B) lower occlusal view, (C) frontal view, (D) right lateral view, (E) left lateral view, and (F) overjet.

for occlusal contacts was provided for each setup: no color = no contact, green = light contact, yellow = normal contact, red = heavy contact.

The subjects were asked to review the images and video clip for each setup carefully before rating the quality of the setups from poor (0) to ideal (100) on a 100-point visual analog scale. If the marker was placed at any point other than ideal, the subjects were asked to select one or more features that led them to give the setup a less-than-ideal rating. The list of features included the ABO cast-based measurements,[2] that is, alignment, marginal ridges, buccolingual inclination, occlusal relationship, occlusal contacts, overjet, and other features commonly considered in evaluating an occlusion such as periodontal concerns, arch form, midlines, angulation, rotations, and overbite. A text box allowed subjects to identify additional unlisted concerns. Last, subjects were asked in which state their main practice was located, how many years they had been practicing orthodontics, and whether they routinely used CBCT scans in treatment planning (Figure 3).

A pilot survey conducted on 10 orthodontists was used to assess the time needed to complete the survey, test the clarity of the questions, and obtain feedback on image and video quality.

Statistical Analysis

A linear mixed effects model with type of view as fixed effect and orthodontist and patient number as random effects was used to assess the effect of the type of view on the mean rating of a setup for all subjects. Interactions between routine CBCT use and type of view as well as years in practice and type of view were added to this model. Logistic regression models with type of view as fixed effect and orthodontist and patient number as random effects were used to evaluate the effect of the type of view in selecting features of concern. The mean difference between ratings for the four duplicate setups was calculated, and the Bland and Altman method[13] was used to assess intrarater agreement. Statistical analyses were performed using SAS 9.4 for Windows (SAS Institute Inc, Cary, NC). *P* values of less than .05 were considered statistically significant. Bonferroni correction was used when multiple comparisons were made.

RESULTS

A total of 7500 AAO members met the inclusion criteria and were contacted by e-mail. Of these individuals, 3000 opened the e-mail, 530 opened the survey website, and 447 answered the screening

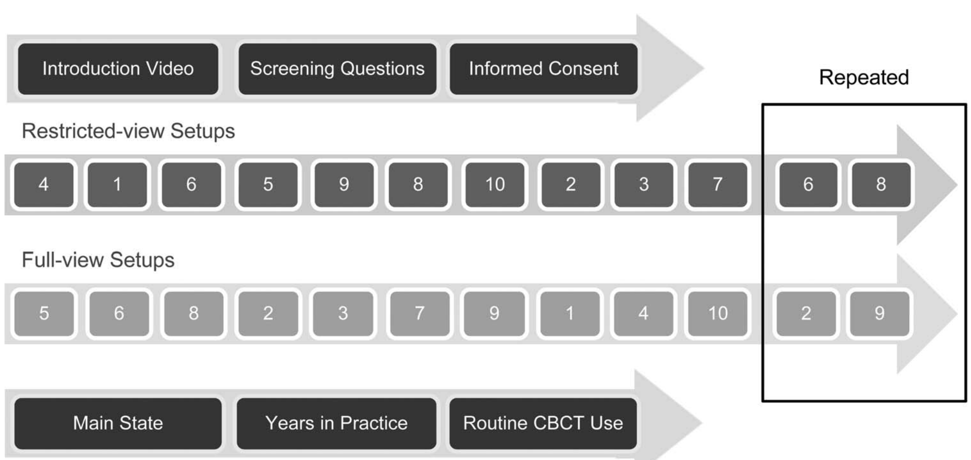

Figure 3. Order of presentation of the various survey elements. Setups shown in duplicate for assessment of intrarater agreement are outlined in black.

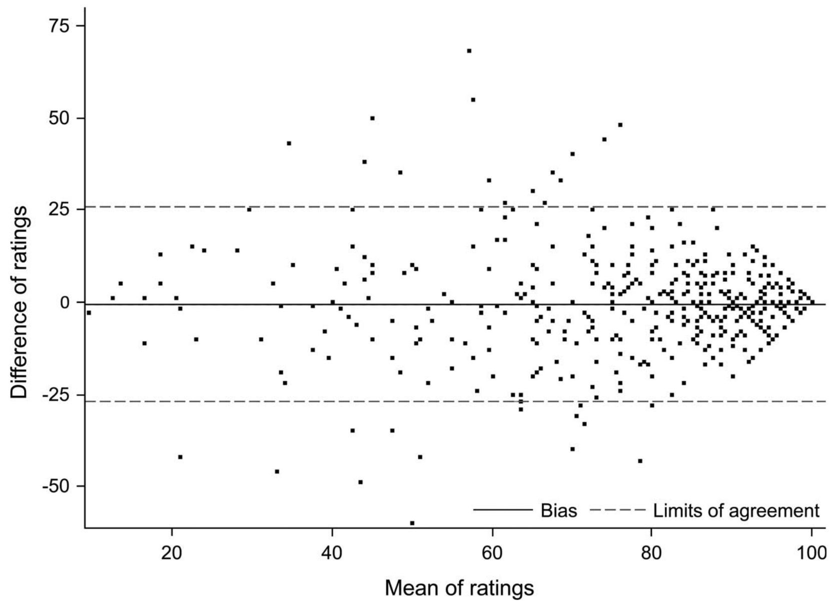

Figure 4. Intrarater agreement. Data points in the Bland-Altman plot represent the difference in setup ratings for identical pairs of setups.

questions. Of these 447 individuals, 115 indicated that they did not feel comfortable evaluating CBCT scans. Eleven subjects did not provide informed consent. Out of the 240 subjects who started answering survey questions, 141 fully completed the survey and their responses are included in the analyses below.

The greatest proportions of respondents were from Minnesota (9.56%), Texas (9.56%), California (5.88%), Illinois (5.88%), Massachusetts (5.15%), and North Carolina (5.15%). Forty percent of the subjects were routine CBCT users, with the greatest proportions being from Minnesota (10.72%), Arizona, California, and Texas (each 8.93%). The practice experience of the respondents ranged from 1 to 42 years (average, 16.8 ± 11.4 years).

Intrarater agreement was high, with a mean difference between ratings for duplicate setups of –0.62 points (95% confidence interval: –2.24, 2.10; $P =$ .5204). Bland-Altman analysis yielded a bias of –0.62 points with 95% limits of agreement of –27.00 and 25.76 (Figure 4).

The ratings for full and restricted views of the setups are shown in Table 1. The ratings were significantly lower when roots and bone were visible ($P <$ .0001). Ratings for full and restricted views of the setups with the data separated by routine CBCT use are shown in Table 2. The interaction between routine CBCT use and type of view was significant ($P =$ .0047), indicating that the effect of type of view on ratings depends on routine CBCT use. More specifically, the visibility of roots and bone in the setups had less effect on the ratings by the subjects who routinely used CBCT for treatment planning purposes. The number of years in practice was not significantly associated with the setup ratings ($P =$ .5757), and the interaction between the number of years in practice and setup ratings did not differ significantly by type of view ($P =$ .1148).

The proportions of subjects selecting features of concern for full and restricted views of the setups are shown in Table 3. Buccolingual inclination and periodontal concerns were selected significantly more often as reasons for a less-than-ideal rating when roots and bone were shown. In contrast, occlusal relationship, overjet, occlusal contacts, and arch form were selected significantly more often as reasons for a less-than-ideal rating when roots and bone were not shown. The odds of selecting periodontal concerns as a reason for a less-than-ideal rating were 331.65 times greater when roots and bones were visible than when not.

DISCUSSION

Visualization of roots and bone, that is, the additional diagnostic information derived from CBCT scans, significantly influenced the raters' perceptions of orthodontic case quality and potentially influenced treatment-planning decisions. When asked to rate the overall quality of the setups, the respondents consistently rated the full-view setups significantly lower than the restricted-view setups. Excellent intrarater agree-

Table 1. Ratings for Full and Restricted Views of the Setups

	Full View	Restricted View	Difference (95% CI*)
Rating	66.97 ± 3.85	79.73 ± 3.85	−12.76 (−14.01, −11.51)

Results are mean values ± standard deviation.
* CI indicates confidence interval.

Table 2. Ratings for Full and Restricted Views of the Setups Separated by Routine CBCT Use

	Full View	Restricted View	Difference (95% CI*)
Routine CBCT use	65.84 ± 4.12	76.40 ± 4.12	−10.56 (−12.54, − 8.59)
Nonroutine CBCT use	67.73 ± 3.97	81.95 ± 3.97	−14.23 (−15.84, −12.61)
Difference (95% CI)	−1.89 (−6.70, 2.91)	−5.56 (−10.36, −0.75)	

Results are mean values ± standard deviation.
* CI indicates confidence interval.

ment indicates that this was not a random occurrence. As the most frequent reason for a less-than-ideal rating with full-view setups was "periodontal concerns," it is evident that visualization of bone alerted the orthodontists to potential periodontal defects. In addition, the pattern in which features of concern were selected suggests that the visualization of the roots alerted orthodontists to the buccolingual inclination of teeth. Conceivably, the visibility of full-length roots, regardless of bone display, revealed differences in buccolingual inclination more clearly than did the truncated roots in the restricted-view setups.

Limiting the visualization of roots and bone appeared to draw the orthodontists' attention to specific occlusal features that were equally visible in both types of view, as occlusal relationship, overjet, occlusal contacts, and arch form were selected more often for the restricted-view setups. Perhaps the eye is drawn to potential periodontal issues in the full-view setups, while occlusal features gain more attention when information about the periodontium is limited.

It should be noted that the periodontal defects depicted in the setups may in reality be less severe. Their appearance in the setups was influenced by the resolution of the CBCT scan, potential partial volume effects, and the algorithm used by the SureSmile software to model the bone. Because of the latter it should be emphasized that bone thickness and fenestration are best evaluated using cross-sectional images, not 3-D surface renderings. Moreover, no osseous changes are simulated with tooth movement. This means that, although CBCT scans have been shown to be reasonably accurate and reliable for detecting bony dehiscences and fenestrations,[14] the appearance of periodontal defects in virtual setups should not be used as a predictor. However, they can alert the orthodontist to potential lack of bone coverage in these areas after the proposed tooth movements.

Interestingly, the visibility of roots and bone in the setups had less effect on the ratings by respondents who routinely use CBCT for treatment planning purposes. This may suggest that routine users feel more comfortable with setups showing bony dehiscences and fenestrations, possibly because they see these frequently. After all, alveolar defects are a common finding, even before orthodontic treatment.[15] It is also conceivable that routine CBCT users are more aware of the potential limitations of bone imaging and modeling as discussed above or that bone will follow tooth movement to some extent. It was also interesting to see that there was no significant association between years in practice and ratings using either type of view.

Regardless of the extent to which periodontal health influences orthodontic treatment-planning decisions, there is no doubt that significant facial bone defects can negatively affect the long-term health of the teeth.[9] While the ABO recognizes the importance of a good periodontal outcome by considering root parallelism, there is currently no consideration of potential peri-

Table 3. Proportions of Subjects Selecting Features of Concern for Full and Restricted Views of the Setups

Feature	Full View	Restricted View	Odds Ratio (95% CI)**	*P* Value
Marginal ridges	9.14	11.71	0.66 (0.49, 0.89)	.0067
Buccolingual inclination	33.79	19.64	2.51 (2.07, 3.05)	<.0001*
Periodontal concerns	60.00	2.93	331.65 (206.52, 532.60)	<.0001*
Occlusal relationships	15.64	23.43	0.50 (0.40, 0.62)	<.0001*
Alignment	10.86	11.14	0.96 (0.73, 1.27)	.7751
Overjet	8.76	12.00	0.64 (0.48, 0.84)	.0016*
Occlusal contacts	37.00	51.36	0.41 (0.34, 0.49)	<.0001*
Arch form	8.86	12.07	0.65 (0.49, 0.85)	.0019*
Midlines	12.36	12.86	0.92 (0.67, 1.25)	.5815
Angulation	14.21	13.50	1.08 (0.85, 1.38)	.5310
Rotations	12.00	10.93	1.16 (0.88, 1.53)	.2937
Overbite	2.86	4.14	0.59 (0.37, 0.96)	.0333
Other	7.29	9.43	0.70 (0.51, 0.95)	.0209

* Statistically significant at Bonferroni adjusted level ($P < .05/13 = .0038$).
** An odds ratio of greater than 1 indicates that the odds of selecting a feature were greater for the full- than for the restricted-view setups.

odontal issues in the buccolingual dimension. The present results suggest that it could be of value to incorporate an additional score to reflect facial bone coverage, especially since this feature seems to strongly influence an orthodontist's perception of a good result.

The inclusion criteria and the time required for survey completion are attributable to two limitations to this study. First, the requirement of being comfortable with evaluating CBCT scans may have influenced the response rate, since CBCT use for orthodontic treatment planning is not yet commonplace. While the use of this technology is recognized for more complex situations, such as impacted teeth,[16] the value of routine CBCT use is not universally accepted.[17,18] This is also reflected in the findings of a recent survey of postgraduate orthodontic programs in the United States and Canada, which found that only 18.2% of the programs used CBCT as a routine diagnostic tool. The remainder reported access to the technology but only occasional use for specific clinical situations.[19] Given the number of US orthodontic practices currently using CBCT imaging, the response rate of this study is surprisingly high. Second, careful evaluation of occlusion takes time, and this time commitment may have increased the dropout rate.

Notwithstanding these limitations, it is evident from the present results that orthodontists' perceptions of the quality of a finished case are influenced by visualizing roots and bone, especially by the alveolar bone coverage over roots. It is plausible that some orthodontists, especially those who expressed periodontal concerns in cases with bony dehiscences or fenestrations, may choose to compromise the quality of the final occlusion in favor of facial bone coverage. Advanced imaging to allow visualization of roots and bone may therefore add a new parameter for orthodontic treatment planning and may improve the quality of treatment outcomes, especially with regard to the periodontium.

CONCLUSIONS

- Orthodontic treatment simulations are rated more critically when roots and alveolar bone are displayed.
- Orthodontists are more critical of buccolingual inclinations and periodontium when roots and alveolar bone are displayed and more critical of occlusal relationships, overjet, occlusal contacts, and arch form when only tooth crowns are visible in virtual setups.
- Routine CBCT users tend to be less influenced by the visibility roots and bone in their rating of a setup.
- Number of years in practice does not influence perceptions of orthodontic case quality.

REFERENCES

1. De Vos W, Casselman J, Swennen GRJ. Cone-beam computerized tomography (CBCT) imaging of the oral and maxillofacial region: a systematic review of the literature. *Int J Oral Maxillofac Surg*. 2009;38:609–625.
2. Casko JS, Vaden JL, Kokich VG, et al. Objective grading system for dental casts and panoramic radiographs. American Board of Orthodontics. *Am J Orthod Dentofacial Orthop*. 1998;114:589–599.
3. Mah J, Sachdeva R. Computer-assisted orthodontic treatment: the SureSmile process. *Am J Orthod Dentofacial Orthop*. 2001;120:85–87.
4. Kihara T, Tanimoto K, Michida M, et al. Construction of orthodontic setup models on a computer. *Am J Orthod Dentofacial Orthop*. 2012;141:806–813.
5. Barone S, Paoli A, Razionale AV. Creation of 3D multi-body orthodontic models by using independent imaging sensors. *Sensors (Basel)*. 2013;13:2033–2050.
6. Müller-Hartwich R, Präger TM, Jost-Brinkmann PG. SureSmile-CAD/CAM system for orthodontic treatment planning, simulation and fabrication of customized archwires. *Int J Comput Dent*. 2007;10:53–62.
7. Larson BE, Vaubel CJ, Grünheid T. Effectiveness of computer-assisted orthodontic treatment technology to achieve predicted outcomes. *Angle Orthod*. 2013;83:557–562.
8. Müller-Hartwich R, Jost-Brinkmann PG, Schubert K. Precision of implementing virtual setups for orthodontic treatment using CAD/CAM-fabricated custom archwires. *J Orofac Orthop*. 2016;77:1–8.
9. 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.
10. Mathews DP, Kokich VG. Managing treatment for the orthodontic patient with periodontal problems. *Semin Orthod*. 1997;3:21–38.
11. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. *J Can Dent Assoc*. 2006;72:75–80.
12. Grünheid T, Kolbeck Schieck JR, Pliska BT, Ahmad AM, Larson BE. Dosimetry of cone-beam computed tomography machine compared with a digital x-ray machine in orthodontic imaging. *Am J Orthod Dentofacial Orthop*. 2012;141:436–443.
13. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1:307–310.
14. Leung CC, Palomo L, Griffith R, Hans MG. Accuracy and reliability of cone-beam computed tomographs for measuring alveolar bone height and detecting bony dehiscences and fenestrations. *Am J Orthod Dentofacial Orthop*. 2010;137:S109–S119.
15. Evangelista K, Vasconcelos KF, Bumann A, Hirsch E, Nitka M, Alves Garcia Silva M. 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–e7.

16. Becker A, Chaushu S, Casap-Caspi N. Cone-beam computed tomography and the orthosurgical management of impacted teeth. *J Am Dent Assoc*. 2010;141;14S–18S.
17. Mah J, Huang J, Choo H. Practical applications of cone-beam computed tomography in orthodontics. *J Am Dent Assoc*. 2010;151:7S–13S.
18. Kapila S, Conley RS, Harrell W. The current status of cone beam computed tomography imaging in orthodontics. *Dentomaxillofac Radiol*. 2011;40:24–34.
19. Smith BR, Park JH, Cederberg RA. An evaluation of cone-beam computed tomography use in postgraduate orthodontic programs in the United States and Canada. *J Dent Educ*. 2011;75:98–106.