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

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Abstract

Introduction: Technological advances in three-dimensional imaging of the dentition have provided orthodontists with more diagnostic information than ever. This study evaluated the effect of root and bone visibility on perceptions of the quality of treatment simulations to assess how the use of advanced imaging such as cone-beam computed tomography (CBCT) may influence treatment planning decisions.

Methods: An online survey was used to present 141 orthodontists with setups (digital models of teeth) generated for 10 patients in 2 different types of view: with and without bone and roots as modeled from a cone-beam computed tomography scan. Using a 100-point visual analog scale, the orthodontists were asked to rate the quality of the setups from poor to ideal, 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 ($P<0.0001$). 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 archform 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.

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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, a feature which was previously difficult to ascertain. Up to now, this is not reflected in the case evaluation system used by the American Board of Orthodontics (ABO) for certification purposes (Casko *et al*., 1998), which places a major emphasis on the final occlusion and draws its scoring criteria from dental models and panoramic radiographs. However, with the expanded knowledge from CBCT, orthodontists have a new form of information to consider and 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 buccal bone coverage, others may utilize the additional information to improve tooth positioning based on a unique perspective on angulation and inclination when roots and bone can be seen.

One relatively new form of technology that uses CBCT data is the SureSmile system (OraMetrix, Richardson, TX). This all-digital system allows orthodontists to create three-dimensional (3-D) setups from digital models and CBCT scans. The orthodontist can then simulate treatment with high-resolution visual information about crowns, roots, and alveolar bone shown either separately or simultaneously (Mah and Sachdeva, 2001). While construction of orthodontic setups blending digital models and CBCT has also been described using other types of software (Kihara *et al*., 2012; Barone *et al*., 2013), the SureSmile system is unique in that it allows fabrication of robotically-bent archwires (Müller-Hartwich *et al*., 2007), which have been shown to produce tooth movements resulting in treatment outcomes similar to those predicted in the setup (Larson et *al*., 2013).

Although the alveolar bone modeled in a digital setup does not currently allow measurement of buccal bone thickness, it may provide a warning sign when large alveolar fenestrations or dehiscences appear with the simulated tooth movements. This way, orthodontists have the ability to alter their occlusal treatment goals by modifying their objectives and mechanics to help reduce the risk of adverse periodontal outcomes. However, the degree to which root and bone visualization in the setups alters tooth positioning decisions remains unclear. A better understanding of its potential advantages is important for the orthodontist to fully consider the risks and benefits of CBCT with its associated ionizing radiation. This is particularly important since SureSmile setups can also be created from intraoral scan data, which provides visualization of the crowns only.

The purpose of this study was to investigate the effect of root and bone visibility on orthodontists' perceptions of ideal tooth position. The results will further our understanding of how visualization of roots and bone at the treatment planning stage influences orthodontists' decisions about tooth placement and, since roots and bone are typically only seen in digital setups obtained from CBCT scans, how the use of advanced imaging may influence treatment planning decisions.

Review of the Literature

CBCT Technology and its Diagnostic Potential

Orthodontic treatment planning requires a thorough appraisal of the cranial base, jaws, and dentition in all three dimensions. Until recently, orthodontists have had to cognitively construct these 3-D structures from conventional 2-D radiographs, plaster models of the dental arches, and clinical findings. While these records may be adequate for the treatment planning of many simple orthodontic cases, CBCT technology has allowed orthodontists to assess the structures of the face in a more direct manner (Scarfe *et al*., 2006; Benington *et al*., 2010; Hatcher, 2010).

In addition to the benefits offered for routine treatment planning, this technology has been particularly useful for situations where there are variations in normal anatomy and development, which may affect treatment outcomes (Mah *et al.*, 2010; Kapila *et al.*, 2011). For example, for patients with craniofacial anomalies or significant skeletal asymmetries, the relationships of the different components of the face can be challenging to assess in two dimensions. In cases with impacted teeth, CBCT scans can assist the practitioner in the assessment of level of root resorption of adjacent teeth by allowing slice-by-slice viewing in various dimensions (Becker *et al.*, 2010), which has been shown to be more reliable than evaluating root resorption on panoramic radiographs (Dudic *et al.*, 2009). Moreover, the orthodontist can better assess the risks of bringing the tooth into the arch and can identify the ideal direction of traction so that efficient biomechanics can be designed with this direction in mind. Similarly, in cases with supernumerary teeth, the orthodontist can better assess the anatomy and prognoses of the teeth in order to best decide which teeth to retain.

Furthermore, it can be a challenge to understand spatial and anatomic issues concerning the airway and temporomandibular joints with conventional radiographs alone. Orthodontists should carefully analyze the airway region in their diagnostic records, since airway obstruction can significantly affect craniofacial development (Harvold *et al.*, 1981; Woodside *et al.*, 1991). Prior to the advent of CBCT, the upper airway has been measured on lateral headfilms using simple linear measurements and ratios, which may not reflect the complexities of the airway's 3-D structures (Aboudara *et al.*, 2009). Furthermore, osseous abnormalities of the condyle and glenoid fossa complex can be examined with CBCT technology, and referral or further examination made prior to starting orthodontic treatment for unusual findings.

Finally, superimpositions can be made in three dimensions, improving the accuracy in the assessment of growth changes for both treatment planning and research purposes (Larson, 2013). With CBCT volumes, curved surfaces, such as the surface of the cranial base or anterior cranial fossa, can be superimposed to produce detailed 3-D visualizations of the complex changes in these structures with time or treatment (Cevidanes *et al.*, 2006). In addition, multi-planer reconstructions of CBCT volume images provide generally more precise identification of traditional cephalometric landmarks than conventional cephalograms, which allows more precise identification of these landmarks (Ludlow *et al.*, 2009).

For conventional images, slight variations in head position can modify linear and angular measurements, which may influence diagnosis and treatment planning (Malkoc *et al.*, 2005). There are also inherent differences in magnification for each side of the face with a standard cephalogram, which prevents ideal superimposition of even the most symmetric bilateral structures. In contrast, CBCT volumes can be oriented to ideal head position and magnification of the reconstruction can be controlled, with orthogonal projections having been found to provide greater accuracy for midsagittal plane dimensions than conventional cephalograms (Kumar *et al.*, 2014).

Despite the numerous benefits of CBCT for clinical orthodontics, this technology has not yet been widely implemented for routine treatment planning in the United States. There are several likely reasons for this. One major concern is that CBCT scans impart additional radiation exposure when compared to conventional digital radiographs (Garcia Silva *et al*., 2008; Loubele *et al*., 2009; Roberts *et al*., 2009; Qu *et al*., 2010; Grünheid *et al.*, 2012). Given the higher radiation dose, it is critical that the ALARA principle ('As Low As Reasonably Achievable') is balanced with the aforementioned benefits (De Vos and Swennen, 2009). For instance, a single high-resolution CBCT scan exposes a patient to a higher effective dose than the combination of a digital panoramic radiograph and lateral cephalogram (Grünheid *et al.*, 2012). However, multiple radiographs, as indicated for more complex cases, particularly a full-mouth series of radiographs, can add up to a similar of radiation to a CBCT scan (Ludlow *et al.*, 2006). Issues of liability for the orthodontist, with regards to detecting all potential pathologies in the field of view, are also a concern. Referral to an oral radiologist for full evaluation of a CBCT volume is a prudent procedure to avoid issues of missed diagnoses.

Digital Technology in Orthodontics

Digital technology has rapidly gained prominence in orthodontics, with digital photographs, intraoral scanners, and digital models having become important parts of many practices. Digital study models can be produced using chairside intraoral scanning technology, obviating the requirement for routine alginate impressions. Intraoral scanners can eliminate some of the shortcomings of traditional alginate impressions, many of which are associated with impression inaccuracy and an unpleasant patient experience (Farah and Brown, 2009; Grünheid *et al.*, 2014). Other accepted methods for creating digital models include CBCT scanning of alginate impressions or plaster models, and reconstruction of models from CBCT data (Hernandez-Soler *et al*., 2011; Wiranto *et al.*, 2013).

Digital models offer several benefits over traditional plaster models. For instance, the electronic form takes up little to no storage space, can be effortlessly retrieved and reproduced, and can be easily transferred between colleagues. There is no risk of chipping, breakage, or degradation over time (Bell *et al*., 2003; Peluso *et al*., 2004; Rheude *et al*., 2005; Gracco *et al*., 2007; Naidu *et al*., 2009; Kau *et al*., 2011). With regards to the accuracy of the models for orthodontic use, evaluation on digital models has been found to be only slightly different than with plaster models, with clinically acceptable accuracy (Leifert *et al.*, 2008; Grünheid *et al*., 2014).

The ease by which the setups can be manipulated offers an additional advantage for treatment planning. Diagnostic setups can be created within minutes, and offer the orthodontist a useful aid to visualize and simulate a final occlusal result for a patient. While creation of such a setup previously required physical sectioning of plaster models, sectioning can now be easily performed on a computer. Furthermore, cross-sectional views can be created and the models can be magnified for careful analysis or demonstration to patients.

SureSmile System

Some of the most impressive benefits of digital model technology are exemplified in the SureSmile system (OraMetrix, Richardson, Texas). This system combines digital setup technology with wire-bending robotic machinery to help to facilitate treatment (Müller-Hartwich *et al*., 2007). Following initial alignment, leveling, and space closure, digital setups allow the orthodontist to virtually place the teeth in an ideal final position.

Archwires are then bent robotically to these specifications, with the expectation that these will allow tooth movement towards the simulated occlusion. The final occlusion has been shown to be very similar to that planned in the setup (Larson *et al*., 2013). Some studies have also found that SureSmile shortens treatment time (Saxe *et al*., 2010; Alford *et al*., 2011; Sachdeva *et al*., 2012), which may be related to improved treatment planning, improved treatment execution, or a combination of these. There is also evidence to support a higher quality of treatment result when compared to conventional edgewise treatment according to the case evaluation system used by the American Board of Orthodontics (Saxe *et al*., 2010; Alford *et al*., 2011).

The digital setups generated using the SureSmile system can be constructed from intraoral scan data or CBCT data. Only CBCT-derived models show modeling of the roots and alveolar bone and allow the orthodontist to manipulate the setup to view these structures from all dimensions during planning of their treatment. While both forms of the setups show the occlusal relationships of the crowns of the teeth and allow a thorough assessment of the quality of the occlusion, only the CBCT-derived setups offer an indication of alveolar bone coverage of the roots, dehiscences, and fenestrations of the alveolar bone. The accuracy of CBCT scans for measuring alveolar bone height and detecting bony dehiscences and fenestrations has been assessed (Evangelista *et al*., 2010; Leung *et al*., 2010). However, the accuracy of the simulated bone in the setups is not entirely clear, as this information is proprietary to Orametrix and subject to set density levels for segmentation of tissue types. Nevertheless, many orthodontists use CBCT scans to gain information related to the patient's periodontal situation to aid with their treatment planning.

Periodontal Implications of Orthodontic Treatment

Assessment of a patient's periodontal status prior to starting orthodontic treatment is necessary to ensure that tooth movement will not exacerbate periodontal disease. A periodontal screening examination should be completed at every initial orthodontic consultation, with referral to a periodontist for further evaluation and treatment if problems are identified (Mathews and Kokich, 1997). Despite an initial periodontal examination, early dehiscences and fenestrations may exist that cannot be seen in conventional radiographs. These are important to recognize, given that dehiscences and fenestrations are common in adult orthodontic patients (Evangelista *et al.*, 2010). Significant bone loss is associated with attachment loss and a poorer periodontal prognosis, which may be related to tooth mobility and possible premature tooth loss (Novak *et al*., 2015). Furthermore, subjacent alveolar bone dehiscences with overlying unsupported gingiva are associated with gingival recession (Löst, 1984; Richman, 2011) and can lead to exposure of the root surface. Exposure of the root surface can be clinically significant as it may lead to root caries, sensitivity, pulpitis, and possible loss of vitality (Carranza & Camargo, 2015). Additional recession can also cause oral hygiene problems and esthetic issues (Fiorellini *et al.*, 2015).

While bone around the alveolar socket will generally remodel as tooth movement occurs, tooth movement in the context of reduced alveolar bone thickness can worsen existing problems (Fiorellini *et al.*, 2015). Defects in the buccal plate are particularly likely for treatment involving transverse expansion of the arches or excessive proclination or protrusion of the incisors – movements that may be required when patients with severe space deficiencies are treated without extractions. While many patients may prefer a non-extraction treatment option, the potential periodontal defects must be considered. CBCT imaging of alveolar morphology prior to starting orthodontic treatment may help detect areas of potential dehiscence or fenestration, allowing the doctor to identify the most appropriate treatment plan for long-term periodontal health of the teeth (Larson, 2012).

Orthodontic treatment can also improve periodontal health. Ease of plaque removal is a very common benefit to improved alignment, that can help reduce a key etiologic factor in periodontal disease. Orthodontics can help prevent stripping of gingiva from an anterior single tooth crossbite or trauma to the palate from an impinging deep bite (Nasry and Barclay, 2006; Proffit, 2007). It can also be beneficial in more complex periodontal conditions; for example, hemiseptal defects can be improved with uprighting of a molar (reviewed in Mathews and Kokich, 1997).

Outcomes Assessment

The assessment of orthodontic treatment outcomes has traditionally been an issue of discussion among orthodontists as the perception of a treatment results are very subjective. While some clinicians may put more emphasis on function and occlusal features, others may tailor their treatment goal towards maximizing esthetics. In an effort to make the assessment of treatment outcomes more objective, indices such as the Peer Assessment Rating (PAR) index have been introduced (Richmond *et al*., 1992). The PAR index is a fast and simple way of assessing the standard of orthodontic treatment that an individual provider is achieving. With respect to interpreting the results, a mean PAR score improvement of greater than 70% represents a very high standard of treatment. Less than 50% shows an overall poor standard of treatment and less than 30% means the patient's malocclusion has not been improved by orthodontic intervention. It must be stressed, however, that the index is designed to look at a large group of patients rather than an individual patient's outcome. Moreover, the PAR score is related to the patient's initial malocclusion, generally describes the improvement that occurred rather than the quality of the final result, and may not reveal minor flaws in tooth position (Dyken *et al*., 2001; Ponduri *et al*., 2011; American Board of Orthodontics, 2012).

Another assessment tool, which places a major emphasis on the final occlusion and draws its scoring criteria from dental models and panoramic radiographs, is the ABO's case evaluation system (American Board of Orthodontics, 2012). The ABO officially initiated the use of a grading system in 1999 following extensive field tests (American Association of Orthodontics, 2012). The system was developed to assist examinees for board certification in scrutinizing their own finished cases in order to select cases with excellent final occlusions for presentation (Casko *et al.,* 1998). It is often used in the orthodontic literature as a measure of the quality of a final occlusion.

The ABO's OGS (later renamed Model Grading System, MGS) consists of eight criteria (American Board of Orthodontics, 2012). Seven of these criteria are assessed using models and a specialized measuring gauge: alignment, marginal ridges, buccolingual inclination, occlusal relationships, occlusal contacts, overjet and interproximal contacts. Root angulation is assessed on a panoramic radiograph. The ABO OGS does not currently consider any criteria relating to 3-dimensional root position or buccal bone coverage of teeth. Thus, a case with widespread fenestrations, dehiscences, and gingival recessions, could still score highly, indicating a high quality treatment outcome, using this method of assessment. The present work set out to investigate if additional diagnostic information, such as root and bone visibility, has an influence on orthodontists' perceptions of ideal tooth position and quality of treatment result.

Aims and Hypotheses

The overall aim of this project was to evaluate if orthodontists' perceptions of the quality of a finished orthodontic case are influenced by visualization of roots and bone. The specific aims were:

1. To determine if the ability to visualize the roots and bone around the teeth influences the overall quality rating given to an orthodontic setup.
2. To determine whether reasons given for a less-than-ideal rating differ between setups with and without visualization of roots and bone.
3. To evaluate if number of years in orthodontic practice or routine CBCT use have an effect on the overall quality rating or the reasons given for a less-than-ideal rating.

The project tested the following null hypotheses:

1. The overall quality rating given to an orthodontic setup is not influenced by the ability to visualize the roots and bone.
2. There is no difference in the reasons given for a less-than-ideal rating between setups with and without visualization of roots and bone.
3. Years in orthodontic practice and routine CBCT use do not have an effect on the overall quality rating or the reasons given for a less-than-ideal rating.

Materials and Methods

Recruitment of Study Subjects

The research protocol had been approved by the Institutional Review Board at the University of Minnesota (Study Number 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 of America. Subjects were excluded if they had no email address listed in the directory or if they had any other status associated with their AAO membership, such as 'student' or 'retired'. The subjects were contacted by email with a link to a customized survey hosted by an online survey platform (Qualtrics, Provo, UT). The subjects were able to complete the survey anonymously on their personal computer or mobile device using a modern browser of their choice. No time restriction was imposed and the subjects were able to intermit, save, and return to the survey if they chose not to complete it in one session. Two reminder emails were sent to those who did not opt out from future communication.

Following a brief introduction to the survey, the subjects were asked to disclose whether they felt comfortable evaluating CBCT scans for orthodontic treatment planning purposes and whether they were currently in orthodontic residency. Any subjects who identified themselves as not comfortable evaluating CBCTs or as orthodontic residents were redirected from the survey. A consent information form was presented as a downloadable and printable PDF file to those who passed the screening process and the subjects were asked to confirm their consent. The subjects were unable to proceed without confirming that they had read the form and provided informed consent.

Orthodontic Treatment Simulations

Setups were generated for 10 patients who met the inclusion criteria of Angle's 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 as well as brackets and bands 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 ten setups, six images and one video clip were generated (Image capture software: Snipping Tool, Microsoft, Redmond, WA; Video capture software: Debut Pro Edition, NCH Software, Greenwood Village, CO). The images showed upper and lower occlusal views, frontal view, right and left buccal views, and overjet. The videos showed the setup being rotated around a vertical axis near the center of the hard palate 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 to the subjects 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 of the teeth with truncated roots (Figure 2). This view simulated the appearance of a SureSmile setup as generated from direct intraoral scan data. Two setups of each type of view were randomly selected using a random number generator and shown twice in the survey to assess intra-examiner agreement. All restricted views of the setups were shown first, followed by all full-view setups. The order of the setups was randomized within each of these groups, with the condition that setups from the same patient should be separated by at least two other setups to help prevent recognition. A legend of the color code for occlusal contacts as generated by the SureSmile software was provided with each setup (Figure 3).

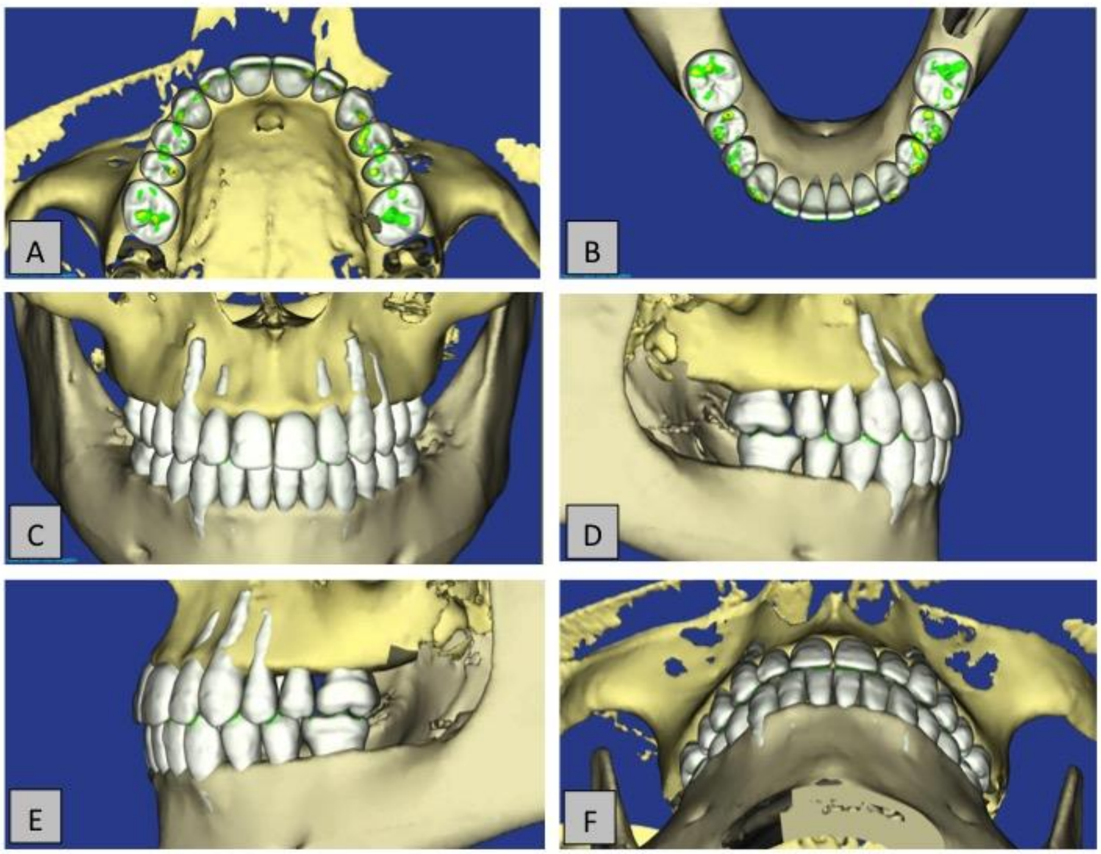

Figure 1. Examples of images generated for a setup with a full view of roots and bone: (A) upper occlusal view, (B) lower occlusal view, (C) frontal view, (D) right buccal view, (E) left buccal view, and (F) overjet.

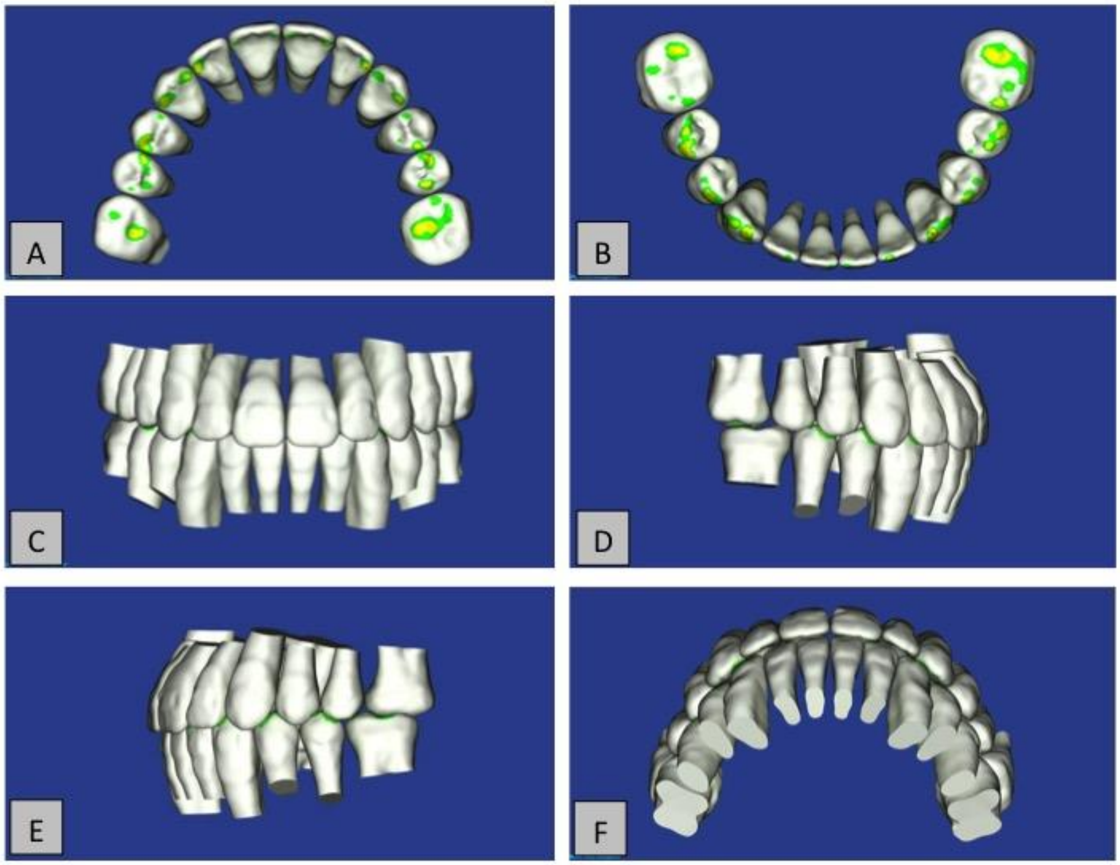

Figure 2. Examples of images generated for a setup with a restricted view, without roots and bone: (A) upper occlusal view, (B) lower occlusal view, (C) frontal view, (D) right buccal view, (E) left buccal view, and (F) overjet.

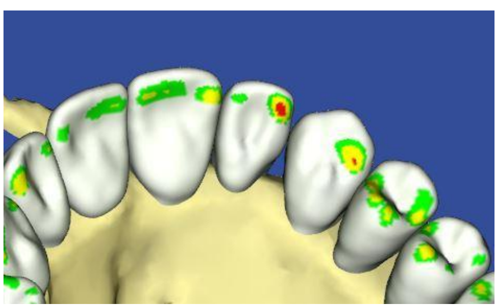

Figure 3. Occlusal contacts. White indicates no contact, green indicates light contact, yellow indicates normal contact, and red indicates heavy contact.

The subjects were asked to review the images and video clip for each setup carefully before answering the associated survey questions. Using a 100-point visual analog scale, the subjects were asked to rate the quality of the setup from poor (0) to ideal (100). If the marker was placed at any point other than ideal, the subjects were then asked to select one or more features that led them to giving the setup a less than ideal rating. The list of features included the cast-based measurements used by the ABO (Casko *et al*., 1998), *i.e*. alignment, marginal ridges, buccolingual inclination, occlusal relationship, occlusal contacts, overjet, and other features commonly considered in the evaluation of an occlusion, such as periodontal concerns, archform, midlines, angulation, rotations, and overbite. A text box allowed subjects to identify additional concerns not listed.

Following presentation of all setups, the subjects were asked to identify the state in which their main practice was located, the number of years that they had been practicing orthodontics, and whether they routinely used CBCT scans for treatment planning purposes.

The order of presentation of various elements of the survey is depicted visually in Figure 4. A pilot survey was conducted on 10 orthodontists and orthodontic residents to evaluate the time needed to complete the survey, test the clarity of the questions, and obtain feedback on image and video quality.

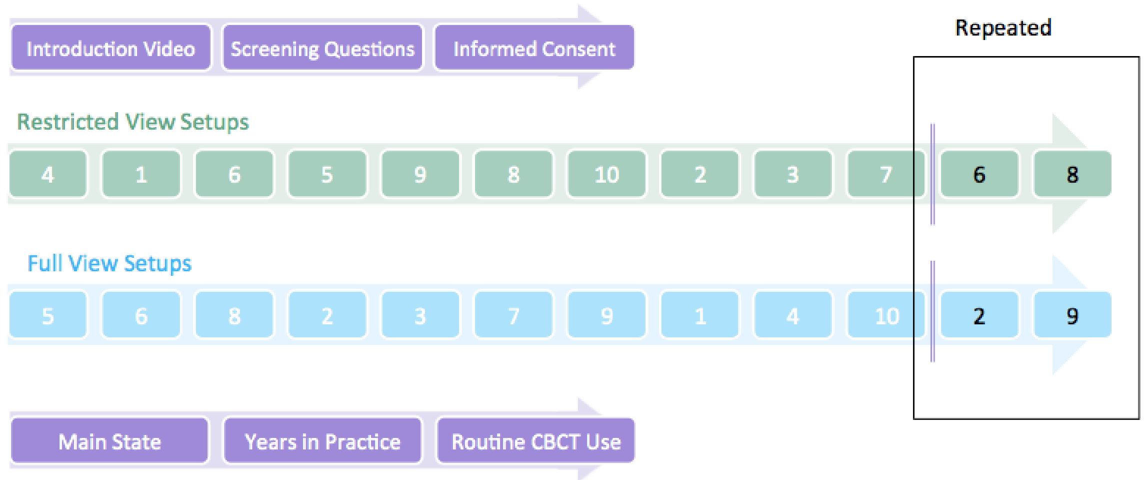

Figure 4. Visual depiction of the survey setup and the order of presentation of the setups. Setups that were shown in duplicate for assessment of intra-examiner agreement are outlined in black.

Statistical Analysis

A linear mixed effects model with type of view as fixed effect and orthodontist and patient case as random effects was used to assess the effect of the type of view (full or restricted) on the mean rating of a setup for all subjects. The 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 case as random effects were used to evaluate the effect of the type of view on the selection of features of concern. The mean difference between ratings for the four duplicate setups was calculated and the Bland and Altman method (1986) was used to assess intra-rater agreement. Statistical analyses were performed using SAS 9.4 for Windows (SAS Institute Inc., Cary, NC, USA). P-values of less than 0.05 were considered statistically significant. Bonferroni correction was used where multiple comparisons were made.

Results

Study Participants

A total of 7500 AAO members met the inclusion criteria and were contacted by email. Of the contacted individuals, 3000 opened the email, 530 opened the survey website, and 447 answered the screening questions. Of these 447 individuals, 115 were unable to proceed with the survey because they indicated that they did not feel comfortable evaluating CBCT scans for orthodontic treatment planning and 2 because they identified themselves as orthodontic residents. Eleven subjects did not provide informed consent. Out of the 240 subjects who started answering survey questions, 141 fully completed the survey (Figure 5) and their responses are included in the analyses below.

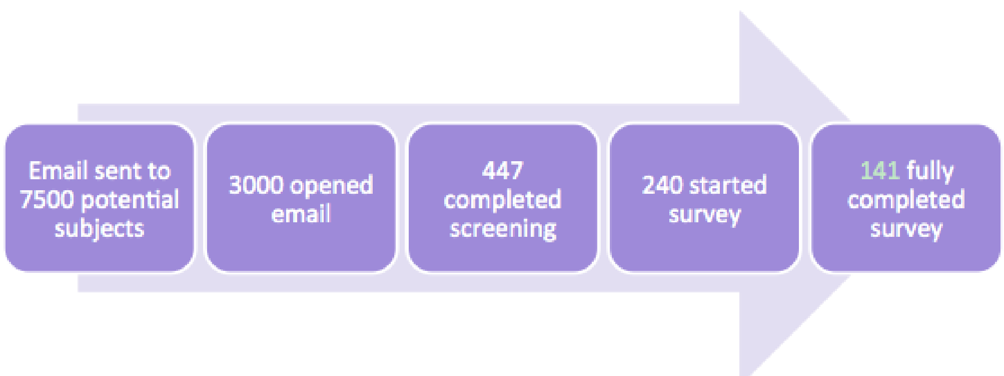

Figure 5. Visual depiction of the number of respondents at sequential stages of the survey.

The greatest proportions of study subjects were from Minnesota (9.56%) and Texas (9.56%), followed by California (5.88%), Illinois (5.88%), Massachusetts (5.15%), and North Carolina (5.15%). Forty percent of the subjects identified themselves as routine

CBCT users. The greatest proportions of routine CBCT users were from Minnesota (10.72%), followed by Arizona, California, and Texas (each 8.93%). The number of years in practice of the subjects who completed the survey ranged from 1 to 42 years, with an average of 16.8 ± 11.4 years.

Intra-rater Agreement

Intra-rater agreement was high with a mean difference between ratings for repeated setups of -0.62 points (95% confidence interval: -2.24, 2.10; P=0.5204). Bland-Altman analysis yielded a bias of -0.62 points with 95% limits of agreement of -27.00 and 25.76 (Figure 6). This indicates that the ratings submitted by participating orthodontists were consistent between presentations of repeated setups.

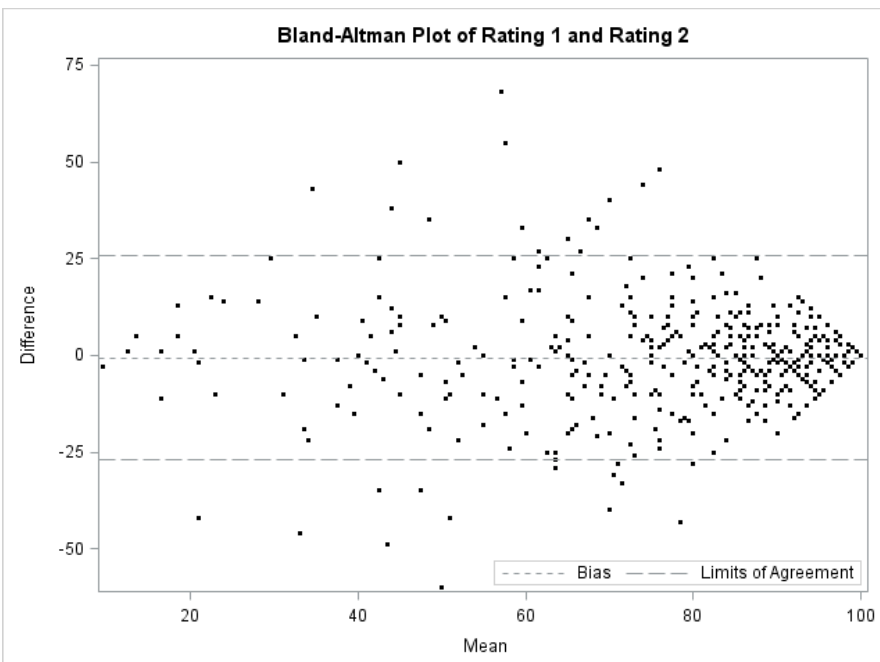

Figure 6. Assessment of intra-rater agreement. Data points in the Bland-Altman plot represent the difference in setup ratings for identical pairs of setups for each subject.

Rating of Treatment Simulations

The ratings for full and restricted views of the setups are shown in Table I. The ratings were significantly lower when roots and bone were visible in the setups (P<0.0001). Ratings for full and restricted views of the setups with the data separated by routine CBCT use are shown in Table II. The interaction between routine CBCT use and type of view was statistically significant (P=0.0047), indicating that the effect of type of view on ratings depends on routine CBCT use. More specifically, there was a lesser difference between ratings for the two view types for routine users of CBCT as compared to non-routine users (10.5 and 14.23 points, respectively). The clinical implication is that the subjects who routinely use CBCT appear to be less influenced in their overall assessment of a setup by the type of view. The number of years in practice was not significantly associated with the setup ratings (P=0.5757), and the interaction between the number of years in practice and setup ratings did not differ significantly by type of view (P=0.1148).

Table I. Ratings for full and restricted views of the setups.

	Full View	**Restricted View**	**Difference (95% CI)**
Rating, Mean (SD)	66.97 (3.85)	79.73 (3.85)	-12.76 (-14.01, -11.51)

Results are mean values (standard deviation) in points along a 100-point visual analog scale. CI, confidence interval.

Table II. 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)
Non-Routine 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) in points along a 100-point visual analog scale. CI, confidence interval.

The proportions of subjects selecting features of concern for full and restricted views of the setups are shown in Table III. 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 archform 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 331.65 times greater when roots and bones were visible than when they were not.

Table III. 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)	0.0067
Buccolingual inclination	33.79	19.64	2.51 (2.07-3.05)	<0.0001*
Periodontal concerns	60.00	2.93	331.65 (206.52-532.60)	<0.0001*
Occlusal relationships	15.64	23.43	0.50 (0.40-0.62)	<0.0001*
Alignment	10.86	11.14	0.96 (0.73-1.27)	0.7751
Overjet	8.76	12.00	0.64 (0.48-0.84)	0.0016*
Occlusal Contacts	37.00	51.36	0.41 (0.34-0.49)	<0.0001*
Archform	8.86	12.07	0.65 (0.49-0.85)	0.0019*
Midlines	12.36	12.86	0.92 (0.67-1.25)	0.5815
Angulation	14.21	13.50	1.08 (0.85-1.38)	0.5310
Rotations	12.00	10.93	1.16 (0.88-1.53)	0.2937
Overbite	2.86	4.14	0.59 (0.37-0.96)	0.0333
Other	7.29	9.43	0.70 (0.51-0.95)	0.0209

* Statistically significant at Bonferroni adjusted level (P<0.05/13 = 0.0038)

** An odds ratio of greater than 1 indicates that the odds of selecting a feature were greater for the full view than for the restricted-view setups

Discussion

This study evaluated orthodontists' perceptions of the quality of a finished orthodontic case with regards to the influence of visualization of the roots and bone. The results suggest that the additional diagnostic information derived from CBCT scans significantly influences the raters' perceptions, and has the potential to influence treatment-planning decisions. To the best of our knowledge, this study is the first to investigate the perception of orthodontic case quality based on the visualization of roots and bone, mimicking the scenario of assessing a setup derived from an intraoral scanner as opposed to a CBCT scan.

When asked to rate the overall quality of the setups, the participating orthodontists consistently rated the full-view setups significantly lower than the restricted-view setups. The excellent intra-rater agreement indicates that this was not a random occurrence. As the reason most often given by the participants for a less-than-ideal rating of the full-view setups was "periodontal concerns", it is evident that visualization of osseous periodontal defects was an important contributory factor to the less favorable rating. 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. It is conceivable that visualization of the full length of the roots, regardless of bone display, revealed differences in buccolingual inclination more dramatically than the truncated roots in the setups with restricted view.

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 setups. For instance, occlusal relationship, overjet, occlusal contacts, and archform were selected more often for the restricted view compared to the full-view setups. It is plausible that, while the eye is drawn to potential periodontal issues in the full-view setups, there is less distraction from these occlusal features when this additional information is not provides as in the restricted-view setups. This suggests that orthodontists may be more likely to scrutinize these occlusal features when the information about the periodontium is limited.

It should be noted that the periodontal defects depicted in the setups may not exist to the shown extent in reality. Their appearance in the setups is influenced by the resolution of the CBCT scan, potential corruption of the outermost voxel layer representing bone by partial volume effects, and the algorithm used by the SureSmile software to model the bone, which is not fully known as it is the manufacturer's proprietary information. However, CBCT scans have been shown to be reasonably accurate and reliable for measuring alveolar bone height and detecting bony dehiscences and fenestrations (Leung *et al*., 2010). Moreover, the appearance of periodontal defects in SureSmile setups is supposed to act as a warning sign to the orthodontist to consider the bone coverage in these areas after the proposed orthodontic tooth movements.

Interestingly, the visibility of roots and bone in the setups had less effect on the ratings by the subjects who routinely use CBCT for treatment planning purposes. This suggests that less frequent CBCT users are more concerned while routine users feel more comfortable with setups showing bony dehiscences and fenestrations, possibly because they see these routinely. After all, it has been shown that alveolar defects are a common finding, even before orthodontic treatment (Evangelista *et al*., 2010). It is also conceivable that these users are more aware of the potential limitations of bone imaging and modeling as discussed above, or believe that the bone will follow to some extent with movement of the teeth towards their final positions. It was also interesting to see that there was no significant association between years in practice and ratings, and this effect was not influenced by the view. Therefore, number of years in orthodontic practice does not appear to significantly influence perceptions of the quality of a setup.

Regardless of the extent to which periodontal health influences orthodontic treatment planning decisions, significant buccal bone defects can negatively impact the long-term health of the teeth (Fiorellini *et al.*, 2015). While the ABO recognizes the importance of a good periodontal outcome by including a root parallelism score in its MGS, there is currently no consideration of potential periodontal issues in the buccolingual dimension. The present results suggest that it could be of value to incorporate an additional score to reflect buccal bone coverage, especially since this feature seems to have a strong influence on orthodontists' perception of a "good" result. While the ABO's MGS has been a reasonable method of case evaluation in the past, it would be desirable for it to evolve with the emergence of new technology such as CBCT.

As a consequence of the inclusion criteria and the time required to complete the survey, there are a couple of limitations to be considered. Firstly, the requirement of being comfortable with evaluating CBCT scans for orthodontic treatment planning may have lowered the response rate, since the use of CBCT for orthodontic treatment planning is not yet commonplace in all areas. While the use of this technology is recognized for more complex situations, such as impacted teeth, the value of taking a CBCT scan for routine treatment planning is not universally accepted (Mah *et al.*, 2010; Kapila *et al.*, 2011). This is reflected in the findings of a recent survey of postgraduate orthodontic programs in the USA and Canada, which found that only 18.2% of the programs used

CBCT imaging routinely as a diagnostic tool, with the remainder having access to the technology but using it only for specific clinical situations (Smith *et al.*, 2011). Given the number of practices in the USA employing CBCT imaging for orthodontic purposes at the time of this writing, the response rate of this study is surprisingly high. Secondly, the evaluation of a final occlusion is something that, if done judiciously, takes time, and the length of time required for careful completion of the survey may have decreased the response rate or increased the dropout rate. It is also conceivable that some study participants' patience wore thin towards the end of the survey and they spent less time on the evaluation of later setups.

While this study attempted to limit the variables influencing the orthodontists' ratings, their preferences with regards to the quality of a setup in reality would likely include an assessment of the esthetic benefits of proclination of the teeth or expansion of the archform. For example, orthodontists may be more accepting of a setup showing less buccal bone coverage of teeth in a patient that would benefit esthetically from greater lip support or reduced buccal corridors. Facial type might also influence their preferences, given that some research has shown a higher prevalence of dehiscence and fenestration in hyper-divergent patients (Enhos *et al*., 2012).

Furthermore, extrapolation of these findings is limited by the threshold levels of density for bone and tooth segmentation set within the SureSmile software. The program generates the appearance of teeth and bone, but the level of density at which a voxel is identified as tooth, bone, or other tissue type is arbitrarily-set and proprietary. This means that the same CBCT scan could generate a very different digital setup on another type of software. For example, if density levels were set to a more sensitive setting for bone segmentation, less dense bone would be visible in setups and would look similar to all other bone within the setup. This could very possibly lead to different results in a similar study. On the contrary, if the set level threshold for bone segmentation is excessively low, orthodontists could compromise their final occlusion based on the appearance of a periodontal defect, where there is in fact only thin or low-density bone.

Notwithstanding the aforementioned limitations, it is evident from the present results that orthodontists' perceptions of the quality of a case are influenced by the visualization of roots and bone, especially by the alveolar bone coverage over the roots. While it remains unknown to what extent these perceptions would influence treatment planning decisions, 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 buccal bone coverage. Advanced imaging to allow visualization of roots and bone may therefore add a new parameter for successful orthodontic treatment planning and may improve the quality of treatment outcomes for patients, especially with regard to the periodontal situation.

Future studies to advance the findings of this research may consider the use of setups that can be freely rotated or those that allow practitioners to freely move teeth to a perceived ideal outcome, to better simulate the use of digital setups in clinical practice. In addition, generating digital setups with defined levels of density for segmentation of various tissue types would lead to findings that could be more easily compared between different software systems.

Conclusions

1. Virtual orthodontic setups are rated more critically by orthodontists when simulated roots and alveolar bone are displayed.
2. Orthodontists are more critical of buccolingual inclination and periodontal concerns when simulated roots and alveolar bone are displayed.
3. Orthodontists are more critical of occlusal relationships, overjet, occlusal contacts, and archform when only able to see the tooth crowns in virtual setups.
4. Routine users of CBCT tend to be less influenced by the visibility of roots and bone in their rating of a setup.
5. Number of years in orthodontic practice does not influence perceptions of orthodontic setup quality.

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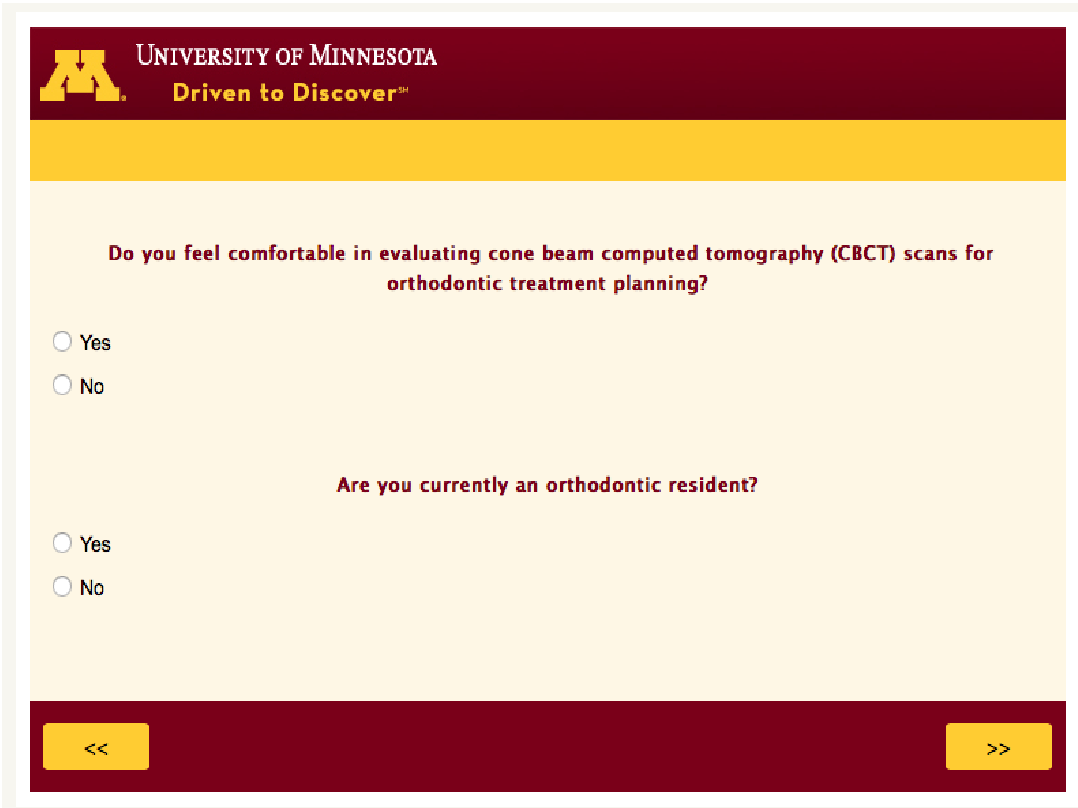
Appendix A: Complete Survey

Screening Questions

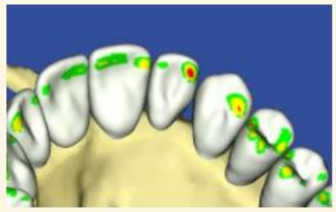


Introduction to the Setups

Contacts are displayed as color changes:

No Color: No Contact **Green**: Light Contact **Yellow**: Contact **Red**: Heavy Contact

Example:



<< >>

Presentation of Setups

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Setup 1

Please review the following images and/or video clip carefully before answering the questions below.
Please feel free to view only photos, only videos, or both.

No Color: No Contact   **Green**: Almost in Contact   **Yellow**: Contact   **Red**: Heavy Contact

Images
- Click to enlarge -

On a scale from "poor" to "ideal", where would you rate the quality of this set up?

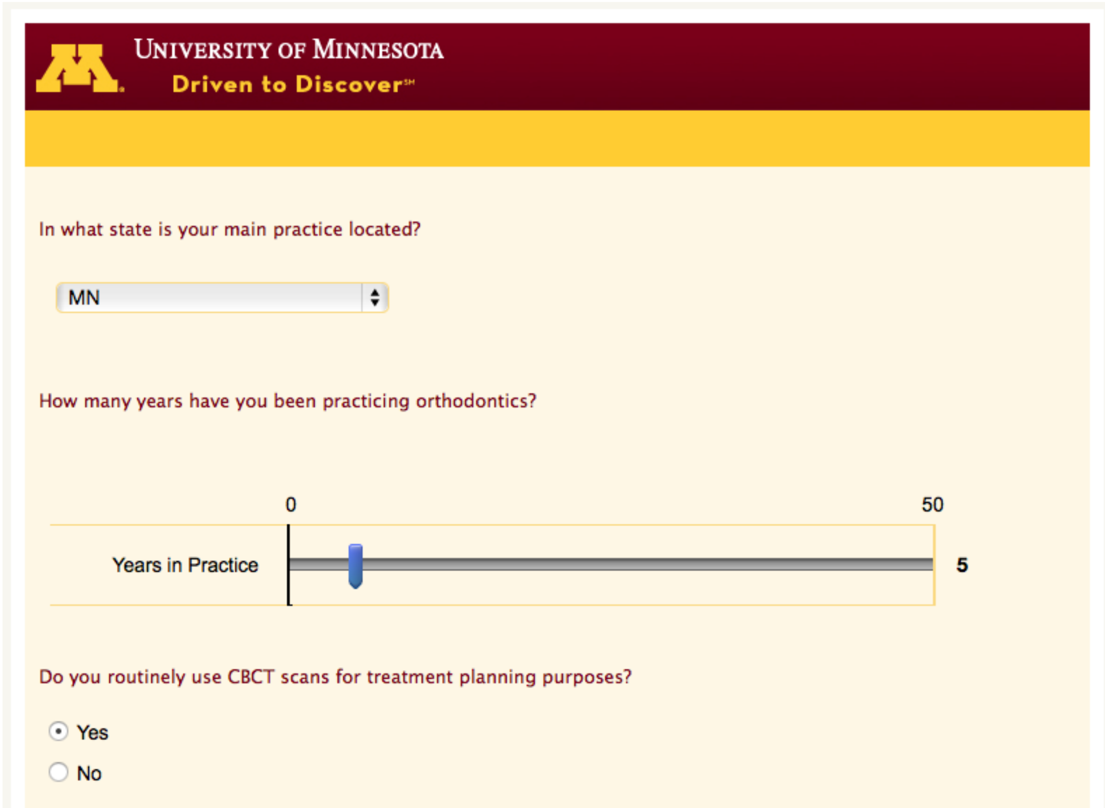
Poor   Ideal

Rating: 64

What feature(s) led you to giving this setup a less than ideal rating?

- ☐ Marginal Ridges
- ☐ Buccolingual Inclination
- ☐ Periodontal Concerns
- ☐ Occlusal Relationship
- ☐ Alignment
- ☐ Overjet
- ☐ Occlusal Contacts
- ☑ Archform
- ☑ Midlines
- ☐ Angulation
- ☐ Rotations
- ☐ Overbite
- ☑ Other Example

Concluding Questions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In what state is your main practice located?

MN

How many years have you been practicing orthodontics?

0 50

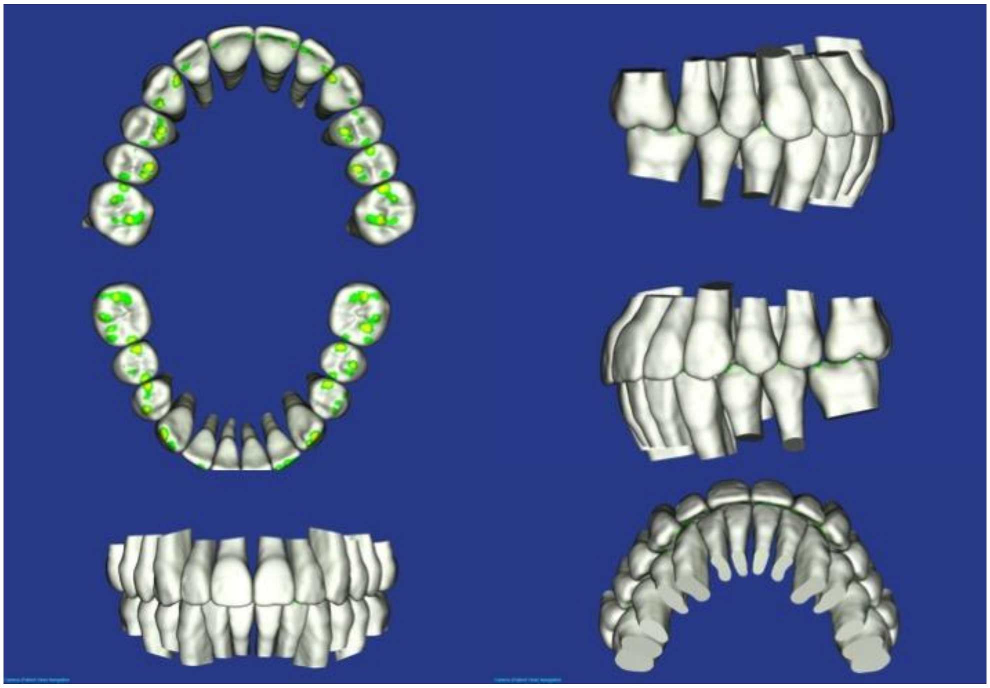
Years in Practice 5

Do you routinely use CBCT scans for treatment planning purposes?

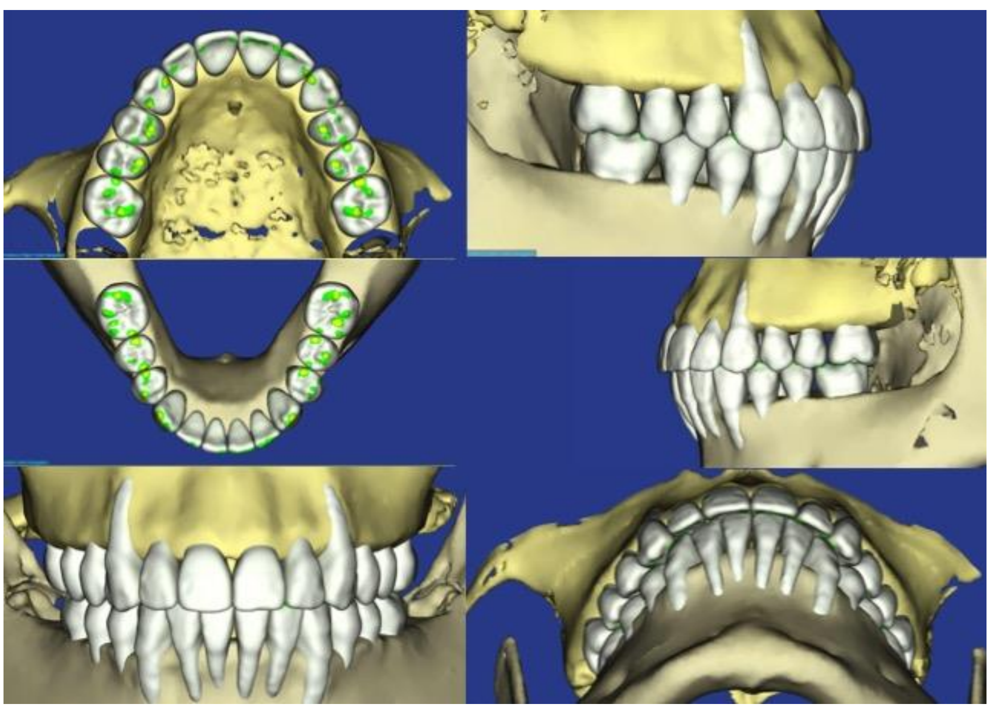
(•) Yes
( ) No

Photos Used

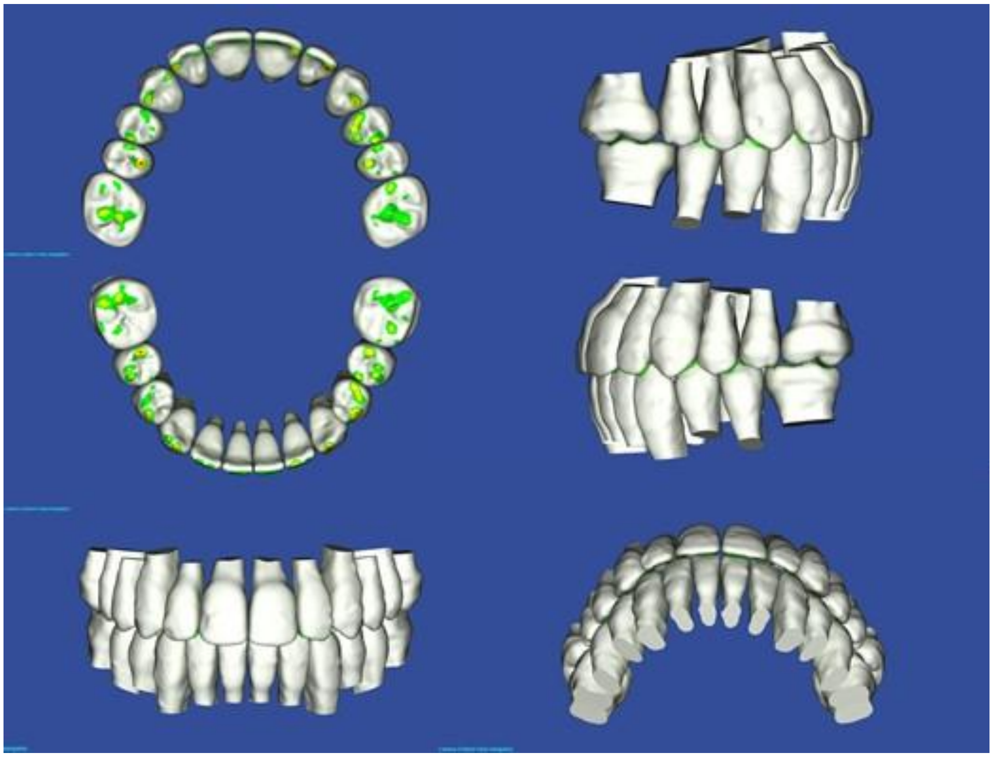
Setup 1 – Restricted View



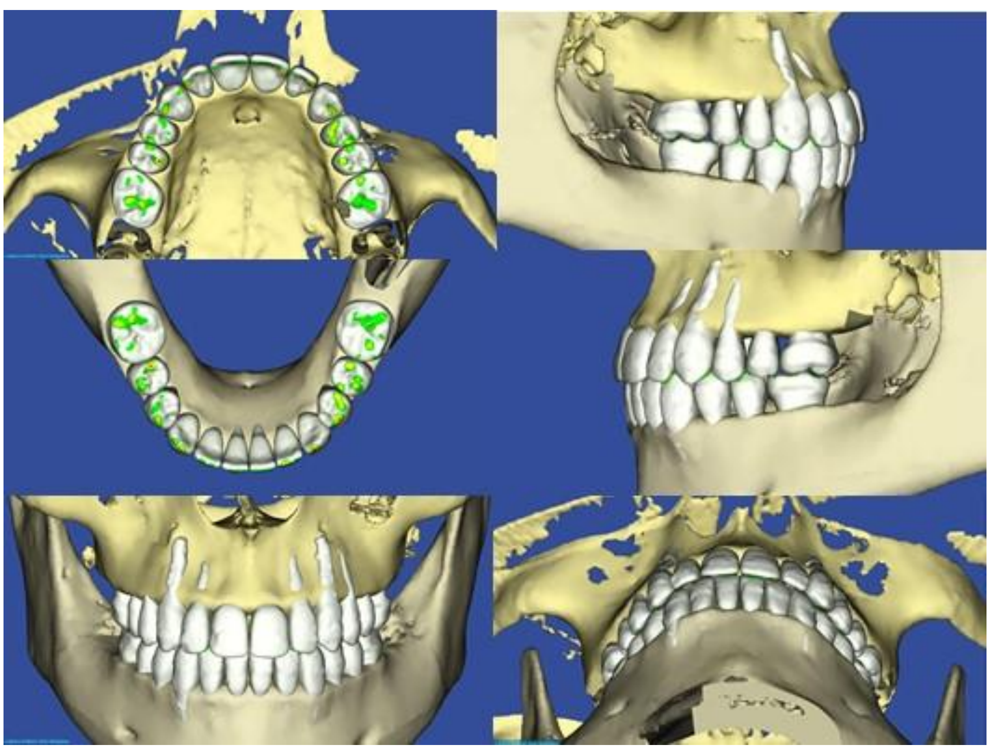
Setup 1 – Full View



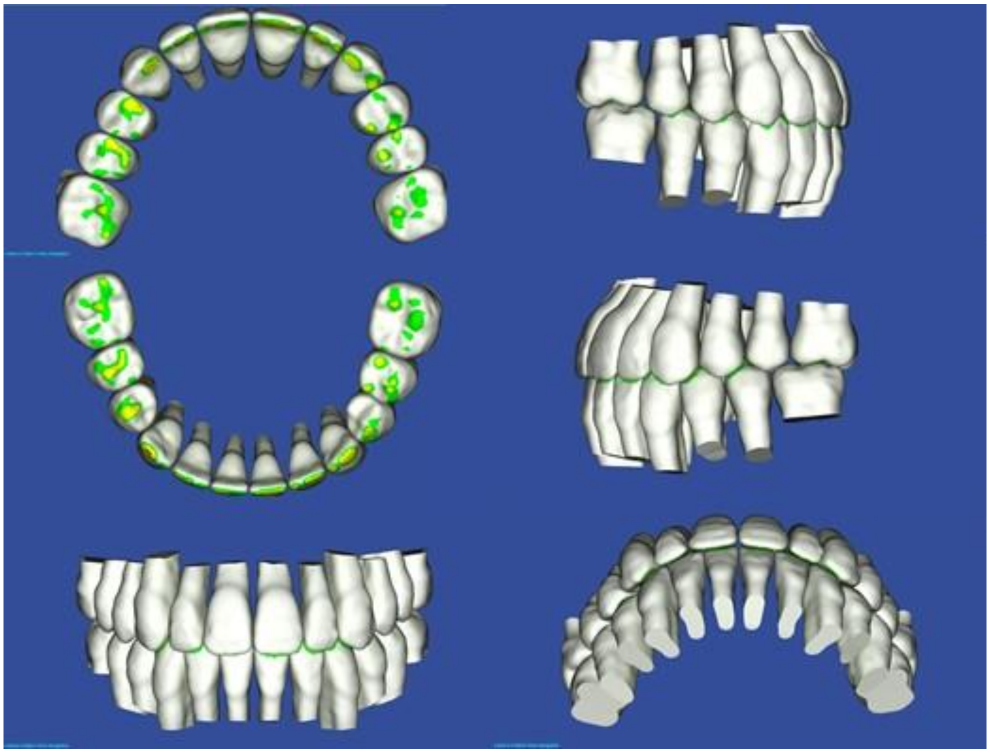
Setup 2 – Restricted View



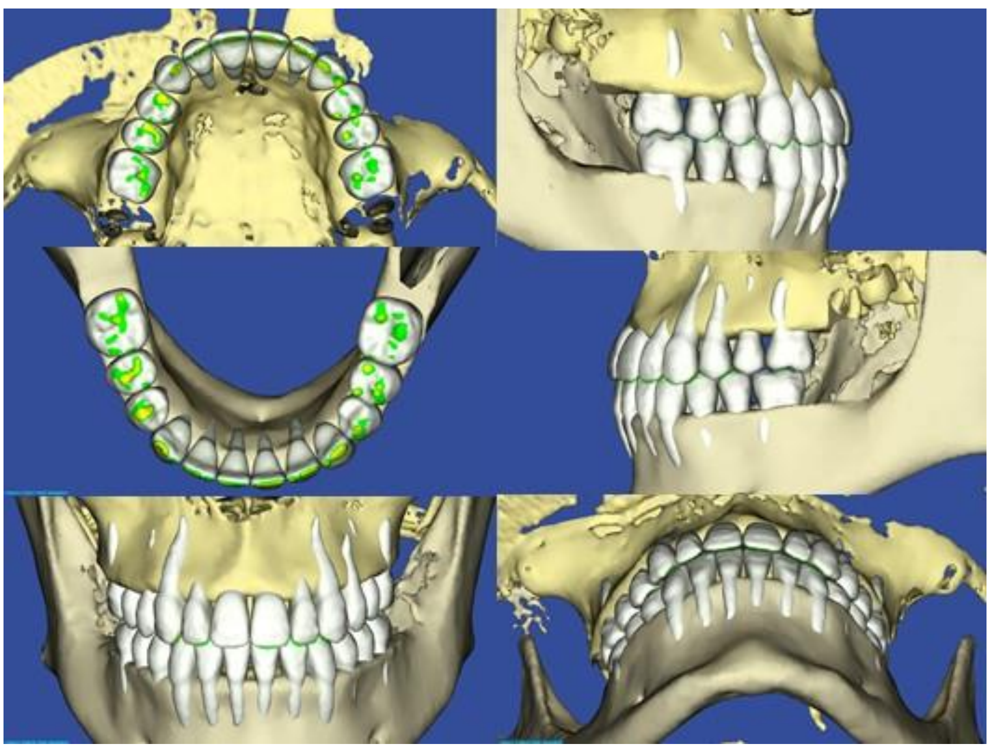
Setup 2 – Full View



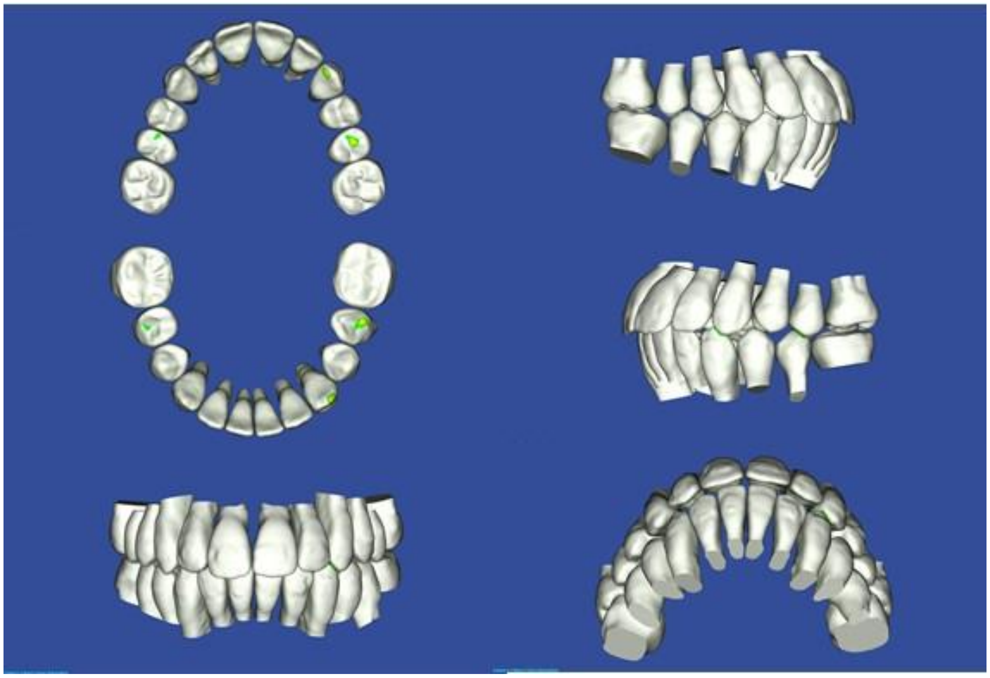
Setup 3 – Restricted View



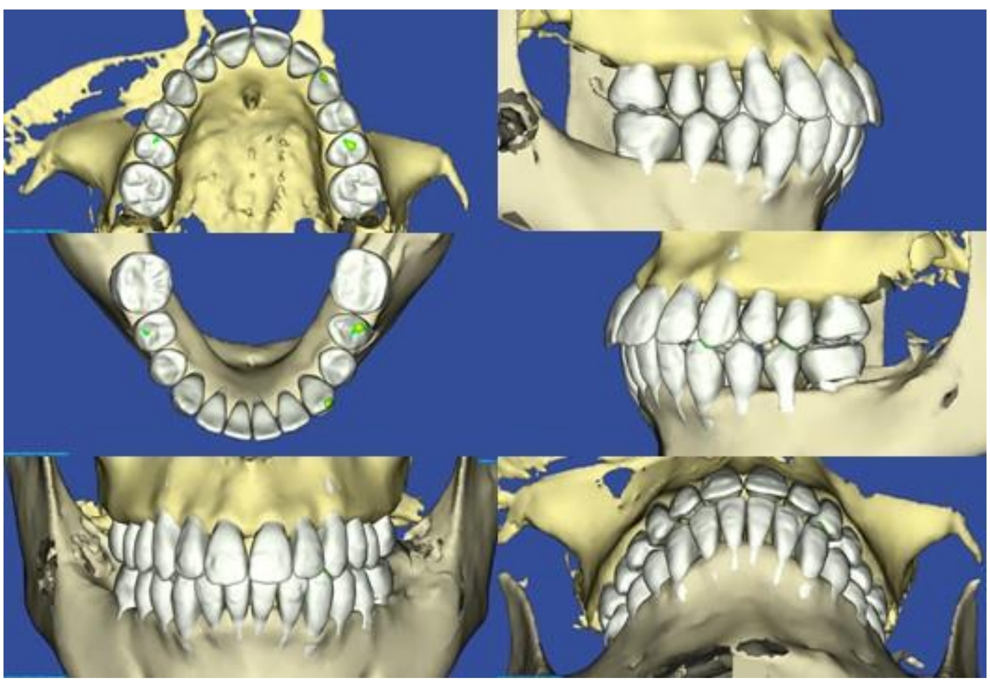
Setup 3 – Full View



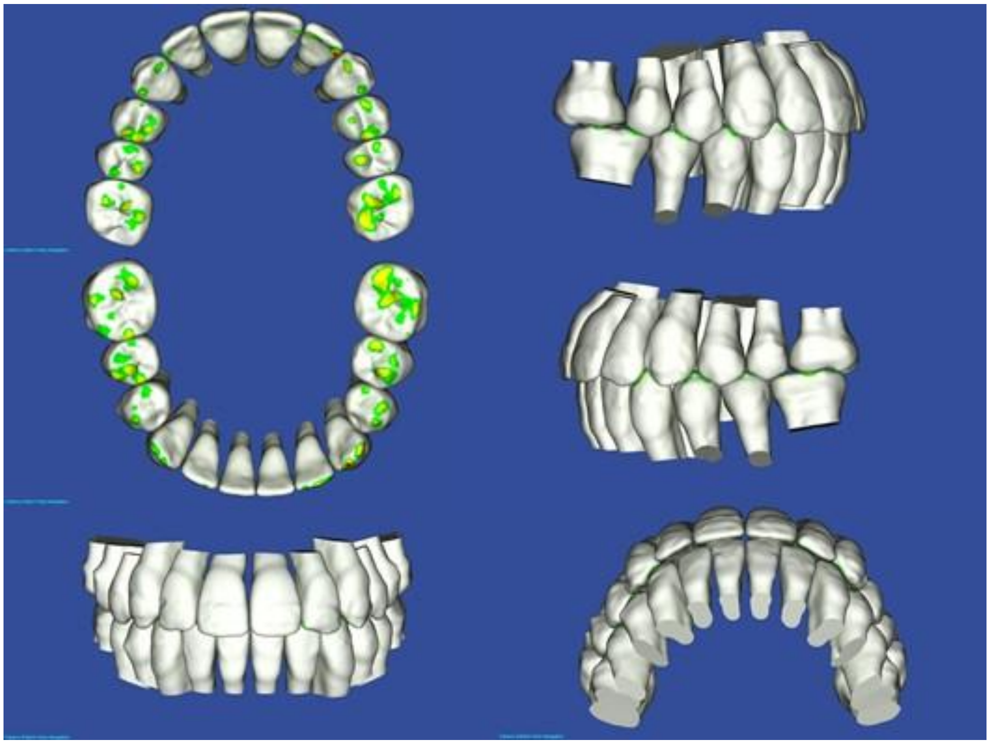
Setup 4 – Restricted View



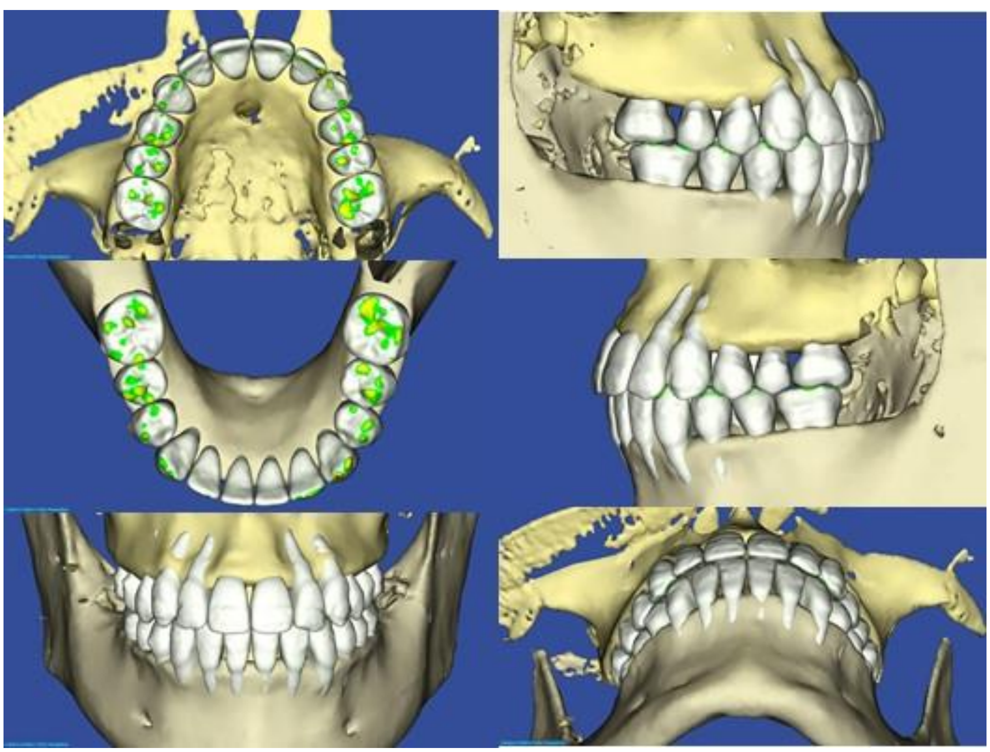
Setup 4 – Full View



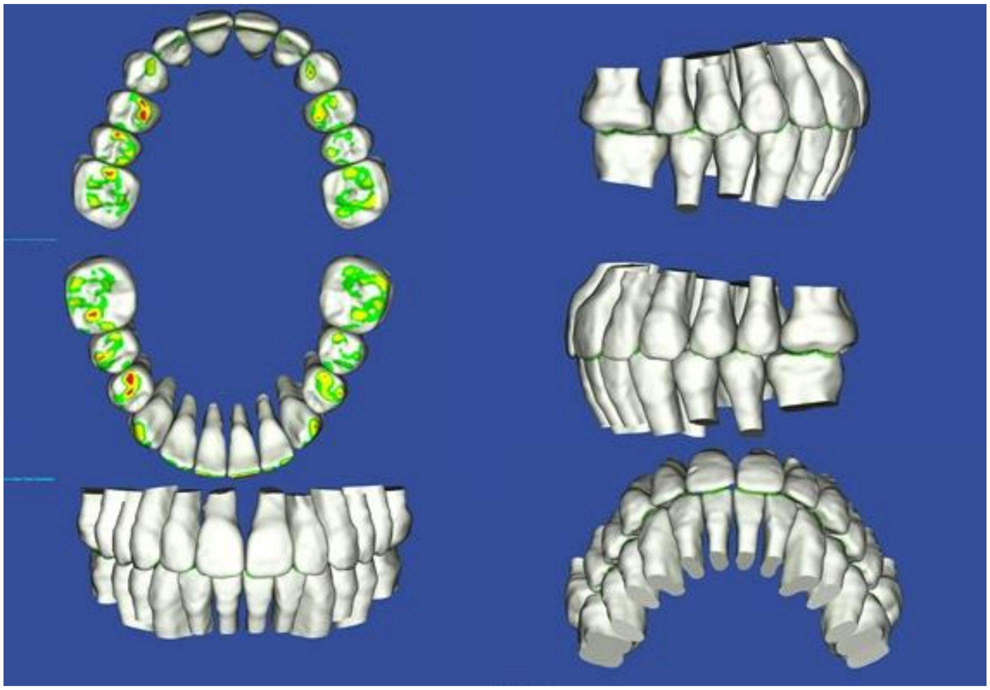
Setup 5 – Restricted View



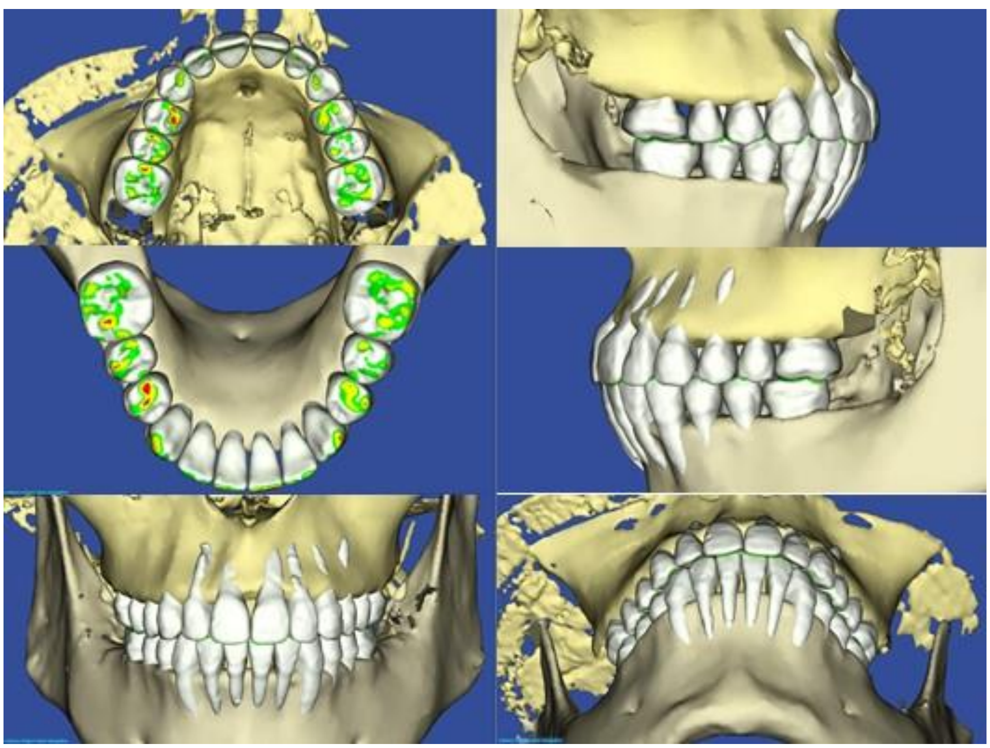
Setup 5 – Full View



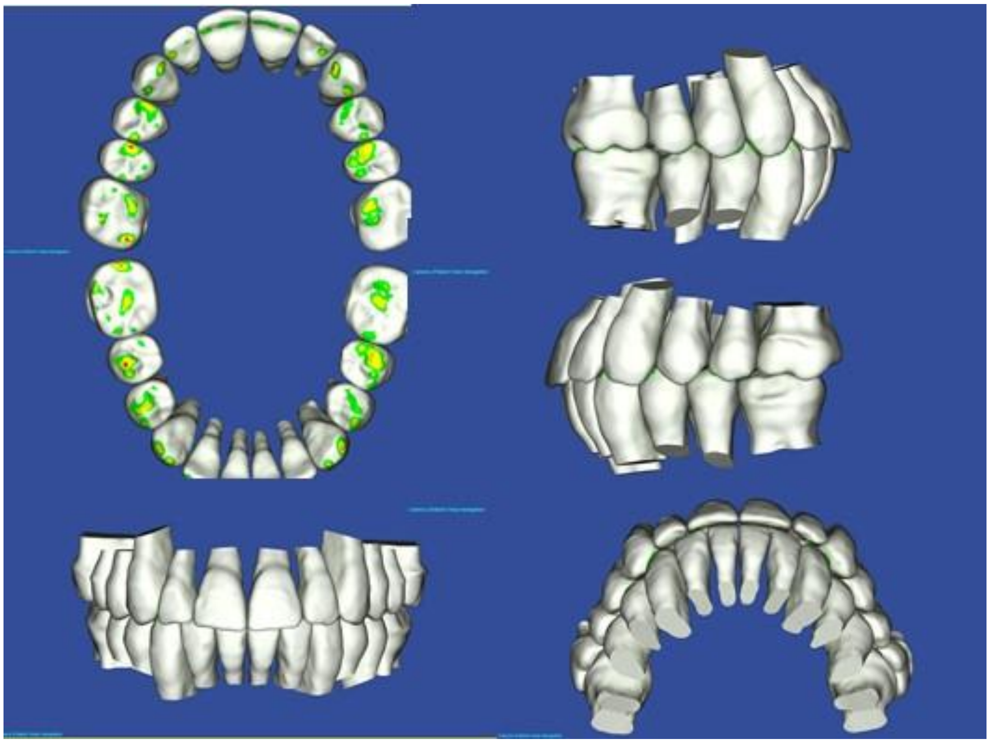
Setup 6 – Restricted View



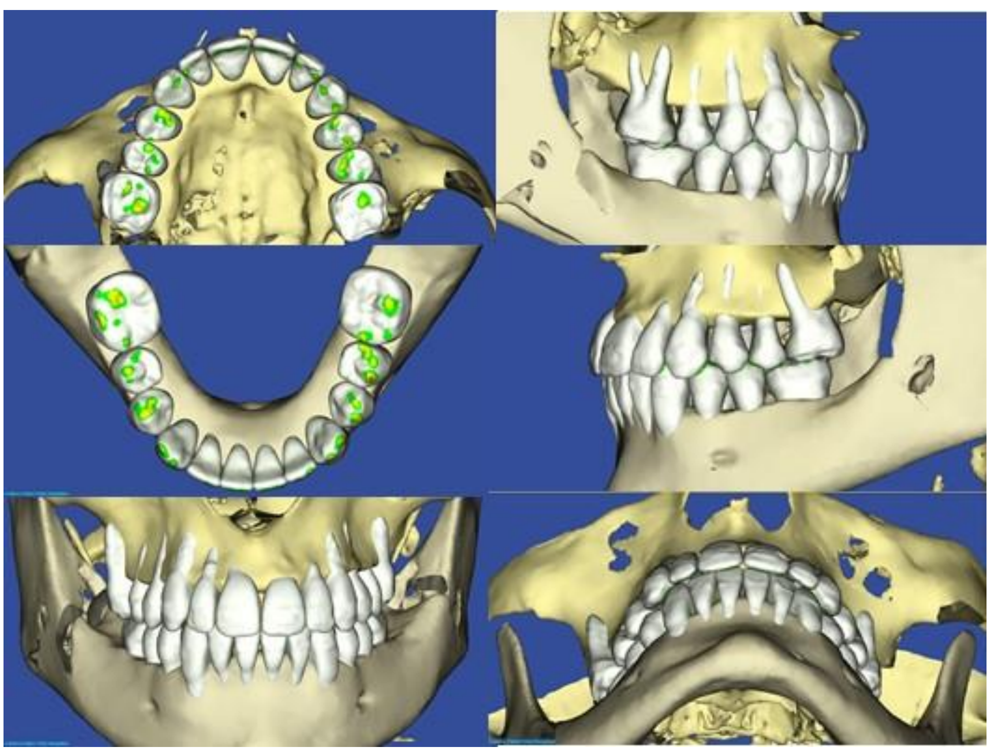
Setup 6 – Full View



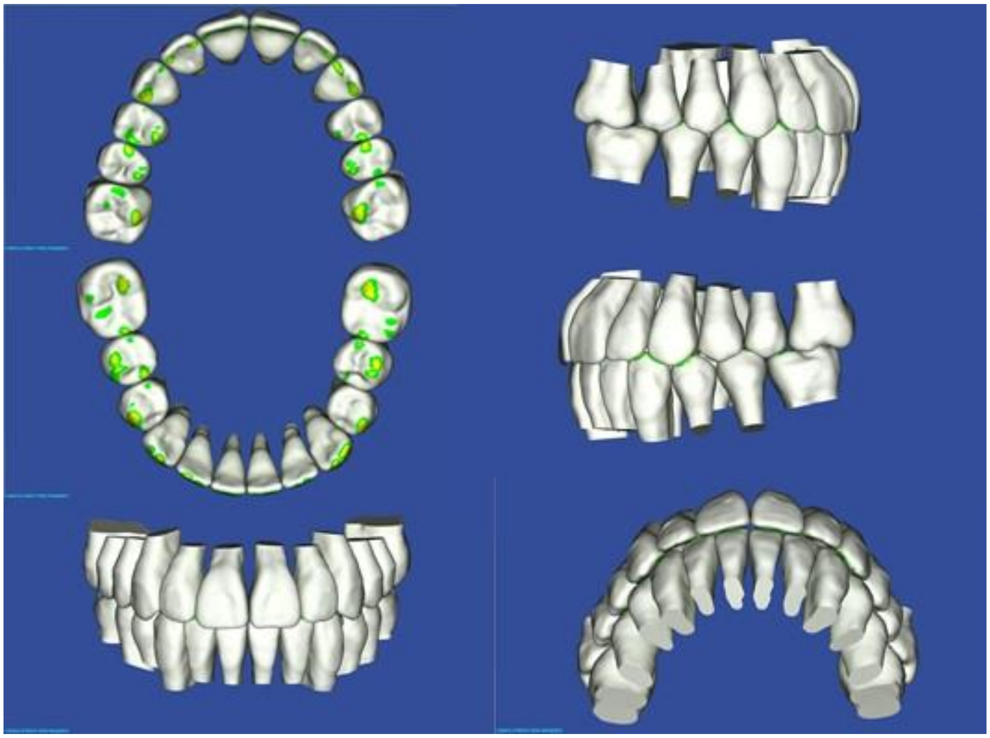
Setup 7 – Restricted View



Setup 7 – Full View

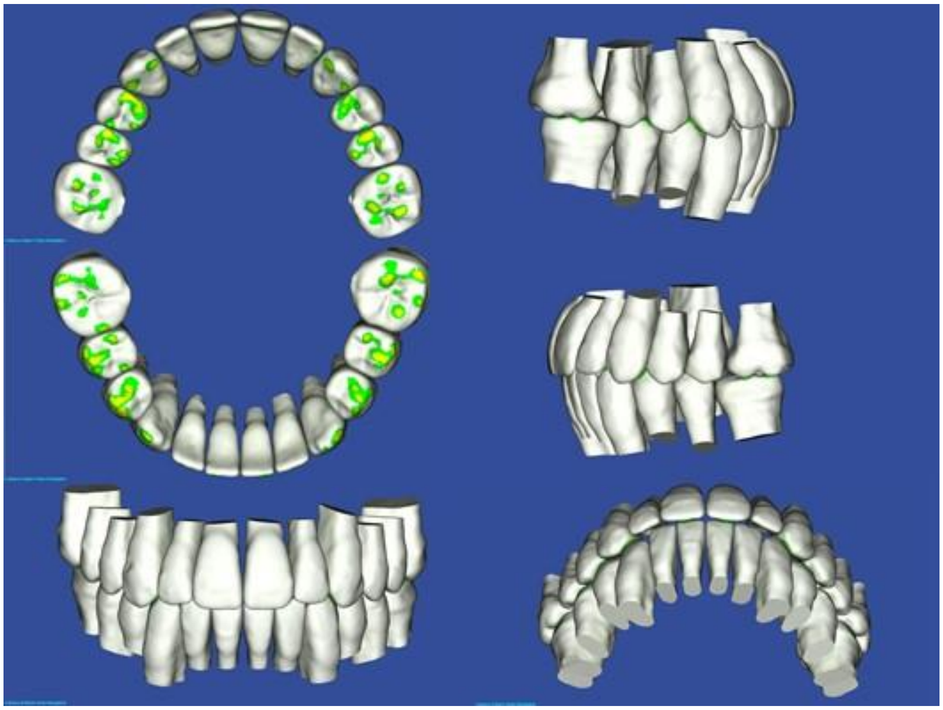


Setup 8 – Restricted View

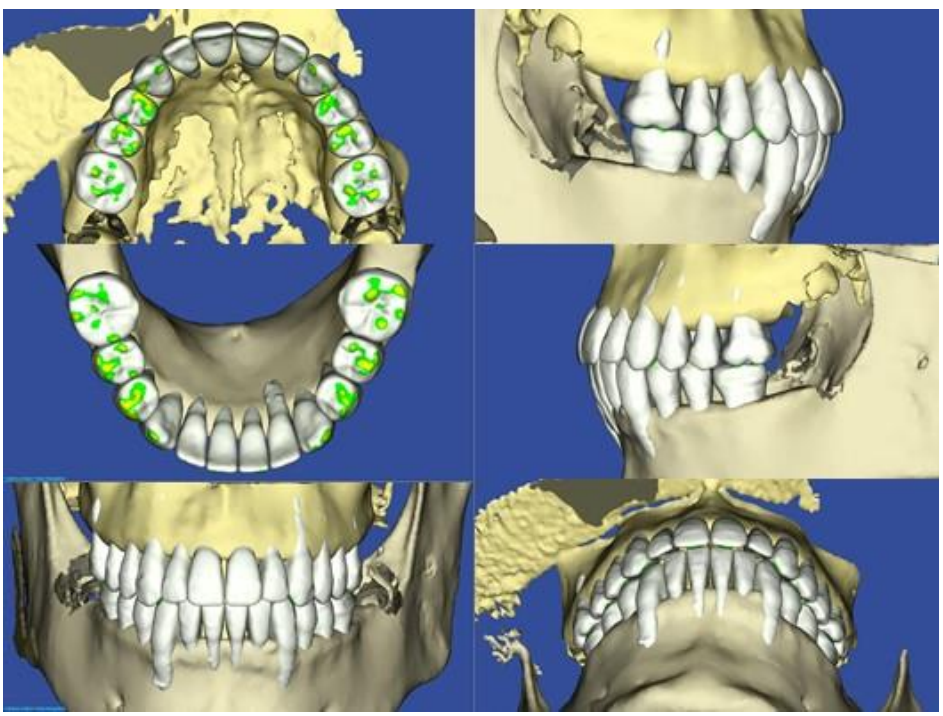


Setup 8 – Full View

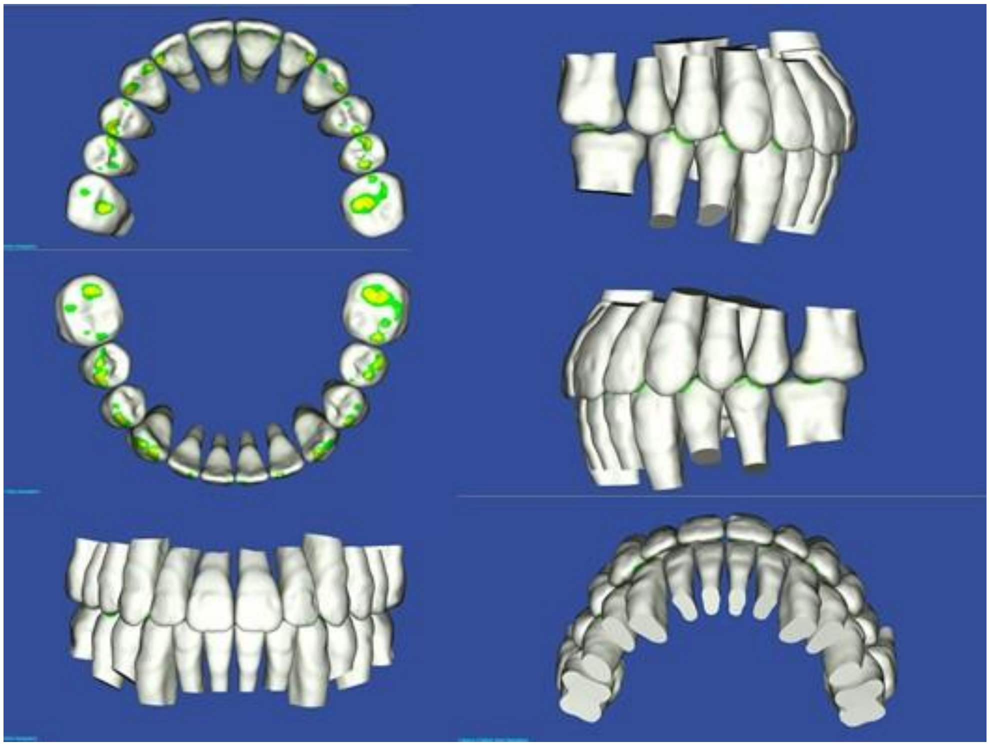
Setup 9 – Restricted View



Setup 9 – Full View



Setup 10 – Restricted View



Setup 10 – Full View