How North Carolina Dentists Use Cone Beam Computed Tomography

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ABSTRACT

JEFFERY B. PRICE: How North Carolina Dentists Use Cone Beam Computed Tomography (CBCT)

Objective. With effective dose levels of three to forty-four times those of panoramic imaging, Oral & Maxillofacial Radiology professionals have the responsibility to ensure proper dental practitioner education and use of CBCT procedures. The present study surveyed dentists practicing in North Carolina who own CBCT machines, regarding their type of equipment, amount of training in CBCT technology, selection criteria for its use, as well as CBCT image interpretation abilities.

Methods. The Radiation Protection Section of the North Carolina Department of Environment and Natural Resources provided a list of all dentist owners of CBCT machines in the state of North Carolina as of May 2009. Thirty-five owners were on the list at that time; they were sent a letter describing the study and requesting their participation. Three practicing Oral & Maxillofacial Radiologists (OMFRs) were also surveyed to serve as controls. Two online surveys were developed. The first survey focused on demographic information, usage of equipment and training background of the participants. The second survey presented screen views from two different volumes of patient data that the practitioners were sent for review. The participants were asked interpretation questions based on those screen views. This study was approved by the UNC Biomedical IRB as study #09-1110.

Results. A total of fourteen non-OMFR practitioners as well as the three OMFRs participated in this study. None of the OMFRs used CBCT for ‘routine radiographic exams’ while 29% of the non-OMFRs use CBCT imaging ‘more than once per day’ for ‘routine radiographic exams.’ While all three OMFRs think that field of view (FOV) adjustment capability is ‘very important,’ 29% of the non-OMFRs think that FOV adjustment capability is ‘not important.’ The major source of non-OMFR CBCT training is an ‘in office company representative.’ The most common use for CBCT imaging is for dental implant treatment planning. In the interpretation section, the OMFRs correctly answered 29 of 30 total multiple choice pathology and anatomy identification questions for a 97% correct score while the non-OMFRs correctly answered 72 of 110 total questions for a 65% correct score.

Conclusions. In this pilot study, it seems that the OMFRs used CBCT technology in a more reliable and clinically effective manner than did the non-OMFRs. Further study of how dentists are using CBCT in their practices is required to increase our understanding of this rapidly changing aspect of dental practice.

ACKNOWLEDGEMENTS

I would like to thank Dr. Bruce Howerton as well as the oral and maxillofacial radiology faculty at the UNC School of Dentistry for suggesting the idea of studying the subject of how dentists in private practice use cone beam CT technology. Thank you for your insights.

I would also like to express appreciation to Dr. John Ludlow and my thesis committee members, who have offered guidance and direction throughout the project. The entire committee has been very helpful and full of suggestions on how to structure surveys to maximize effectiveness as well as provide much needed organizational assistance. Thank you for all your support.

Finally, I would like to acknowledge the support of my family these past three years. Thank you for your thoughts and prayers.

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ABBREVIATIONS

AAOMR…….American Association of Oral and Maxillofacial Radiologists

ADA…………American Dental Association

ALARA……...As Low As Reasonably Achievable

CBCT……….Cone Beam Computed Tomography

CD…………..Compact Disc

CDE…………Continuing Dental Education

CT…………..Computed Tomography

DENR………Department of Environment and Natural Resources

DICOM……..Digital Imaging and Communication in Medicine

FDA…………Food and Drug Administration

FOV…………Field of View

LP/MM………Line pairs per millimeter

MRI………….Magnetic Resonance Imaging

NCRP……….National Council on Radiation Protection and Measurements

OMFS………Oral and Maxillofacial Surgeon

OMFR………Oral and Maxillofacial Radiologist

TMJ………....Temporomandibular Joint

UNC…………University of North Carolina

INTRODUCTION

Cone beam computed tomography (CBCT) was introduced for dentistry by Mozzo et al in 1998 with the commercialization of the first NewTom™[*] CBCT machine, the NewTom 9000™[1]. CBCT technology was a major development in oral and maxillofacial radiology with clinical applications in every area of dentistry [2-6].

Most of the data collection for this study occurred in 2009. The study describes the demographics and training of dentists in North Carolina who have purchased and are using CBCT technology in their offices. In addition, this study provides information on how these dentists are using CBCT imaging in their practices as well as the differences between how Oral and Maxillofacial Radiologists (OMFRs) and non-OMFRs use the technology.

This study is significant on many levels. As an integral part of professional dental education, dentists are trained to provide their own radiological services, support and interpretation. Dentists in private practice have been trained to use selection criteria when ordering radiographic examinations for their patients [7-9]. After the dentist orders the appropriate radiographs, auxiliary personnel expose them, and the dentist then interprets the images. In general dental practice, the majority of radiographs consist of periapical, bitewing and panoramic images. Orthodontists are

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[*] NewTom CBCT machines are distributed by ImageWorks, Elmsford, NY

well-versed in cephalometric, panoramic and skull radiology. Oral surgeons and other practitioners in the hospital setting have varying experiences using advanced imaging techniques such as Computed Tomography (CT), Magnetic Resonance Imaging (MRI) as well as other imaging modalities. Compared to these techniques dental cone beam CT is relatively new, and the dental profession is embracing this technology [1, 10, 11]. It is expected that the numbers of CBCT images made for dental purposes will continue to increase. Currently, dental implant therapy is the major impetus for the growth of dental CBCT; and, there are many other areas in dentistry including orthodontics, periodontics, oral and maxillofacial surgery, oral pathology and endodontics that continue to adopt CBCT imaging. To date, there is no available data to determine how practitioners gain the expertise and experience required to generate reliable and accurate CBCT images and then make comprehensive diagnoses and provide treatment based on these images.

The following factors are directly related to the increased usage of dental CBCT: 1) determination of the selection criteria or desired diagnostic task for a specific patient, 2) evaluation of the volumes of data for the presence of pathology and incidental findings, and 3) justification and optimization of the radiation dose when ordering dental CBCT scans. Depending on the type of scan and unit used, dental CBCT scans can result in a 3 to 44-fold radiation increase to patients when compared to most panoramic imaging techniques [12, 13]. As a profession, we are obligated to place patient safety above our own self interests by ensuring the safe and efficacious use of ionizing radiation in dental practice.

Another significant factor in the use of CBCT includes how practitioners translate their understanding of the diagnostic information contained within three-dimensional CBCT volumes and then apply this information directly to patient care. Examples of this include tasks such as mastery of the viewing software and ability to correlate anatomical landmarks seen in the scan, such as the inferior alveolar canal or orthodontic landmarks, to actual locations in the patient. Specific types of questions facing many practitioners include: 'How precise is the safety zone around the inferior alveolar canal when viewing CBCT scans and planning the surgical placement of a dental implant?' and 'How do I interpret growth and development with three-dimensional CBCT images instead of two-dimensional panoramic and cephalometric images?' Other more global questions include the following: What is the clinical significance if private practitioners are not correctly applying this new knowledge? What is the outcome of clinical treatment if scans are not interpreted correctly? Who is responsible for the education of the practitioners who own and use these machines? What guidelines, if any, should be in place to manage the inherent radiation dosage risks when using advanced imaging techniques such as dental CBCT? What is the future direction of dental CBCT education? How do practitioners address the medicolegal responsibilities associated with dental CBCT imaging?

To our knowledge, there are no published studies in the scientific literature on this subject. The intent of this study is to provide the basis for preliminary answers to these and other questions regarding the future of dental cone beam CT education and use. The results of this study should provide guidance to dental educators, dentists using CBCT technology, dentists contemplating the purchase of dental

CBCT machines, and to CBCT machine manufacturers as they design and manufacture dental CBCT machines.

The research questions for this project are as follows: 1) ‘Do specialty trained OMFRs use CBCT technology differently than non-OMFR trained dentists who operate CBCT machines within their practices?’, 2) ‘Do OMFRs interpret CBCT scans differently than non-OMFR trained dentists who operate CBCT machines in their practices?’, and 3) ‘If so, what are those differences and what is the clinical significance of those differences, if any?’[14] This study is limited to dental practitioners within the state of North Carolina who were registered as owners of CBCT machines in May 2009. The small number of practitioners in this demographic limits the project to an observational study using descriptive statistics; therefore, no classic alternative or null hypotheses will be provided [15].

Materials and Methods

This study is a descriptive, cross-sectional analysis of specialty trained OMFRs and non-OMFR trained dental practitioners who own dental CBCT machines in North Carolina. The sample of OMFRs consisted of three board certified OMFRs practicing within the state of North Carolina. The Radiation Protection Section of the North Carolina Department of Environment and Natural Resources maintains a registration list with the names of dentist owners of dental CBCT machines[16]. This registration list was obtained from the Radiation Protection Section in May 2009 and, as of May 12th, 2009, there were thirty-five non-OMFR CBCT machine owners in North Carolina. Altogether, there were forty-two registered CBCT machines within the state, including the two machines at the UNC School of Dentistry and five CBCT machines owned by OMFRs in private practice.

Using the information provided by the Radiation Protection Section, an introductory letter confirming machine registration as well as a request seeking consent to participate in the study was mailed to all registered machine owners. Follow-up was accomplished by letter, telephone and e-mail contacts for those practitioners who did not respond within the first two weeks. After study participation was confirmed, participants were e-mailed the link to the first part of the online survey; a compact disc (CD) containing the InVivo Dental™[†] viewer and two anonymized patient volumes was then mailed to the participant's office address. If the dentist indicated a preference for SimPlant™[‡] files, the volumes were sent in SimPlant™ format. Several days after mailing the CD, a second e-mail was sent containing the link to the second (interpretation exercise) part of the survey. The University of North Carolina at Chapel Hill has an agreement with Qualtrics™[§], which is a company that administers online surveys[17]. The online surveys used in the study were administered using this University-affiliated company.

The survey consisted of two parts: 1) an anonymous, online survey of demographic questions, type of CBCT machine, etc. (Appendix A) and 2) two volumes of cone beam images for participants to review and a second online survey with anatomy and interpretation questions (Appendix B). These cone beam volumes were purposefully selected to represent normal anatomy and common pathological conditions found in cone beam CT volumes. The purpose of these survey materials was to determine knowledge in areas such as dosimetry, quality control, patient selection criteria, anatomy and pathology in relation to dental CBCT imaging.

The survey questions were grouped based on several criteria and the results of the two groups of practitioners–the OMFRs and the non-OMFR trained practitioners—were analyzed separately. Questions 1, 24, 25, 26, 27, and 28 of the

[†] InVivo Dental is a CBCT viewing software product distributed by Anatomage, Inc., San Jose, CA

[‡] SimPlant is a CBCT viewing and dental implant planning software product distributed by Materialise NV, Glen Burnie, MD

[§] Qualtrics is headquartered in Provo, UT first online survey relate to demographic information such as year of graduation from dental school, type of practice and the amount of CBCT training for the dentist and dental auxiliary responsible for acquiring CBCT images. Another category of questions was the office-specific usage of cone beam technology. Questions 2, 3, 4, 5, 7, 9, 11, 12, 13, 14, 15 and 16 of the first online survey addressed issues such as the number of scans exposed per month, purpose of the scans and selection criteria used when recommending scans, etc. Questions 6, 8, 10, 17, 18, 19, 20, 21, 22 and 23 of the first online survey relate to technical knowledge of CBCT imaging, including radiation dosage per scan and other issues related to the technical aspects of CBCT imaging. The fourth and final category of questions—the entire second survey—relate to the clinical interpretation of cone beam CT images. The images in this part of the study were screenshots taken from the CBCT volumes that were sent by CD after study participation was confirmed.

Due to the small numbers of the sample sizes of the two groups and the lack of a classic null hypothesis, it is not meaningful to formulate inferential statistical observations from the data. Descriptive statistics are used to evaluate the outcome of the surveys and to compare the survey data between groups for the answers to the survey questions.

Results

The following results are divided into the sections of questions as outlined by demographic and practice specific characteristics, type of training, technical knowledge and interpretation of CBCT images as described previously.

Demographic Questions

Year of graduation and type of practice

Three OMFRs and fourteen non-OMFRs answered the demographic questions. There were twenty-one non-OMFR CBCT machine owners who did not participate in the study. The total participation rate for non-OMFR machine owners was 40%. The demographic questions included the year of graduation from dental school, and the length of time the practitioner had used CBCT technology, etc. (Table 1 and Appendix A, question numbers 1 and 24 – 28). The median year of graduation from dental school for the OMFRs was 1985 with a range from 1980 to 2000; the median year of graduation for the non-OMFRs was 1982 with a range from 1968 to 2003. The type of practice question asked ‘How would you characterize your practice?’ Four of the non-OMFR practitioners are periodontists, two are oral surgeons and one is a prosthodontist. Three of the non-OMFR practitioners responded ‘general practice with an emphasis on adult restorative dentistry,’ one responded ‘general or family practice,’ one replied ‘general dentistry with an emphasis on family practice, cosmetic dentistry, adult restorative dentistry, orthodontics and pediatric dentistry,' and two practitioners did not answer this question. The median year of specialty program completion for the seven non-OMFR specialists was 1991 while the median year of completion of OMFR training was 2001. All three of the OMFRs reported using CBCT technology longer than four years while only one of the non-OMFRs had used CBCT technology more than four years. Eight of the eleven non-OMFRs who answered the question regarding length of time using CBCT answered 'two to four years.' Half of the non-OMFRs in the study were specialists and most of the specialists in the study were periodontists.

Table 1: Demographics of study participants

Type of Practitioner	Dental School Graduation Year	Specialty Program Graduation	Length of Time Using CBCT Technology
OMFR	1980	1990	More than 4 years
OMFR	1985	2001	More than 4 years
OMFR	2000	2006	More than 4 years
General Dentist	1982	N/A	2 to 4 years
Prosthodontist	1981	1986	2 to 4 years
General Dentist	1981	N/A	6 months to 1 year
Oral Surgeon	2003	2007	6 months to 1 year
Periodontist	1991	1994	2 to 4 years
Periodontist	1968	1973	2 to 4 years
General Dentist	Unknown	N/A	2 to 4 years
General Dentist	1993	N/A	1 to 2 years
Periodontist	1978	1982	2 to 4 years
Oral Surgeon	1995	2000	More than 4 years
General Dentist	1982	N/A	1 to 2 years
Periodontist	1989	1991	2 to 4 years
General Dentist	1977	N/A	6 months to 1 year
General Dentist	1984	N/A	2 to 4 years

There were six general dentists, eight oral surgeons, five periodontists, one prosthodontist and one orthodontist in the non-OMFR CBCT machine owners group who did not participate in the study. Their median year of graduation was 1986 (Table 2).

Table 2: Demographics of study non-participants

Type of Practitioner	Dental School Graduation Year	Specialty Program Graduation	Length of Time Using CBCT Technology
General Dentist	1988	N/A	?
Periodontist	1986	?	?
Oral Surgeon	Unknown	?	?
General Dentist	1984	N/A	?
Oral Surgeon	1990	?	?
Periodontist	1975	?	?
Periodontist	1996	?	?
Periodontist	1979	?	?
Oral Surgeon	1984	?	?
General Dentist	1994	N/A	?
General Dentist	1962	N/A	?
Periodontist	1977	?	?
Oral Surgeon	Unknown	?	?
Prosthodontist	2003	?	?
General Dentist	1994	N/A	?
Oral Surgeon	1986	?	?
Orthodontist	1988	?	?
Oral Surgeon	Unknown	?	?
Oral Surgeon	1972	?	?
Oral Surgeon	2003	?	?
General Dentist	Unknown	?	?

Interest in continuing dental education in CBCT

Eleven of the fourteen non-OMFR practitioners responded that they would be interested in attending continuing dental education (CDE) in CBCT imaging at the UNC School of Dentistry, if it were made available. Eight of the eleven respondents said a four to six hour course would be preferable, as compared to eight or sixteen hour length courses. The suggested topics for the CDE course included primarily pathology and implant dentistry; however, other topics included rare findings, image modification, different scanning protocols, and uses of CBCT.

Office-Specific Use of CBCT Imaging

The second section of questions related to the specific use of cone beam imaging within individual offices. Questions included how long the office had owned a CBCT machine, brand of machine owned, type of software used, etc. (Appendix A, question numbers 2 – 5, 7, 9, 11 – 16).

Length of time for machine ownership

Five non-OMFR practitioners reported owning a CBCT machine for ‘6 months to a year’, one reported ‘1 to 2 years’, seven reported ‘2 to 4 years’ and 1 reported ‘more than 4 years.’ All of the OMFRs reported owning a CBCT machine for longer than four years. The three OMFRs reported using five different machines: iCAT Classic™[**], iCAT Next Generation™[††], Gendex CB 500™[‡‡], Galileos Sirona™[§§] and the NewTom 3G™[***]. The fourteen non-OMFR practitioners reported owning the iCAT Classic™, Galileos Sirona™, iCAT Next Generation™, Planmeca™[†††] and Gendex (Figure 1).

[**] iCAT Classic is distributed by Imaging Sciences International, Hatfield, PA
[††] iCAT Next Generation is distributed by Imaging Sciences International, Hatfield, PA
[‡‡] Gendex CB 500 is distributed by Gendex Dental, Des Plaines, IL
[§§] Galileos Sirona is distributed by Sirona USA, Charlotte, NC
[***] NewTom 3G is distributed by ImageWorks, Elmsford, NY
[†††] Planmeca is distributed by Planmeca Oy, Helsinki, Finland

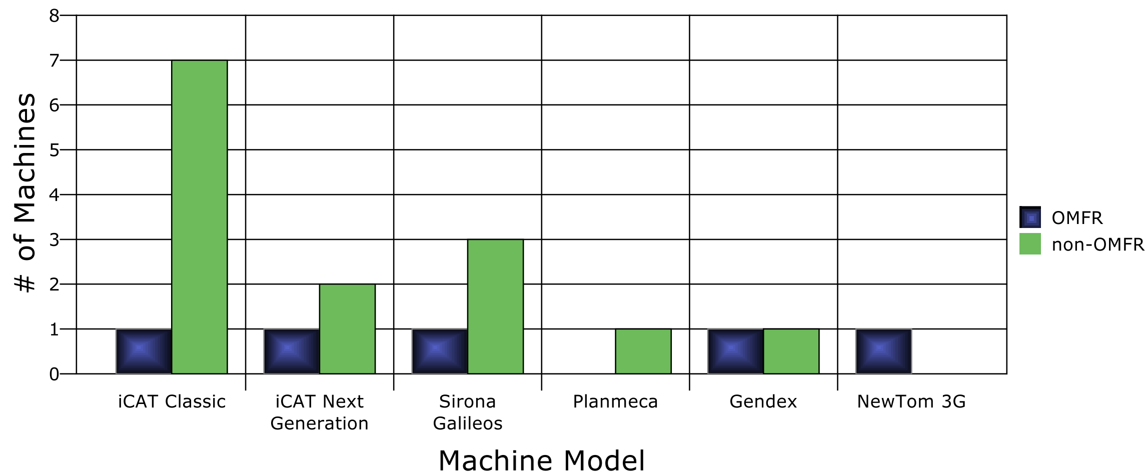


Figure 1. CBCT Machine Ownership by OMFRs and non-OMFRs

Viewing software

The OMFRs reported using OnDemand3D™[‡‡‡], SimPlant™, Xoran™[§§§], Galileos™ and InVivo Dental™ viewing software for CBCT interpretation. Five of the non-OMFRs reported using Xoran™, four reported using iCAT Vision™[****], four reported using SimPlant™, three reported using Galileos™, one reported using Romaxis™[††††] and one reported using Keystone™[‡‡‡‡].

Number of scans exposed per month

All three OMFR practitioners reported making 'more than 25' scans per month, while the non-OMFR practitioners reported making scans throughout the

[‡‡‡] OnDemand3D is distributed by Cybermed, Irvine, CA
[§§§] Xoran is distributed by Xoran Technologies, Ann Arbor, MI
[****] iCAT Vision is distributed by Imaging Sciences International, Hatfield, PA
[††††] Romaxis is distributed by Planmeca Oy, Helsinki, Finland
[‡‡‡‡] Keystone is distributed by Keystone Dental, Burlington, MA

entire range of ‘0 to 5’ to ‘more than 25’ scans per month. As seen in Figure 2, most non-OMFR offices that own a CBCT machine reported making ‘16 to 20’ cone beam CT scans per month.

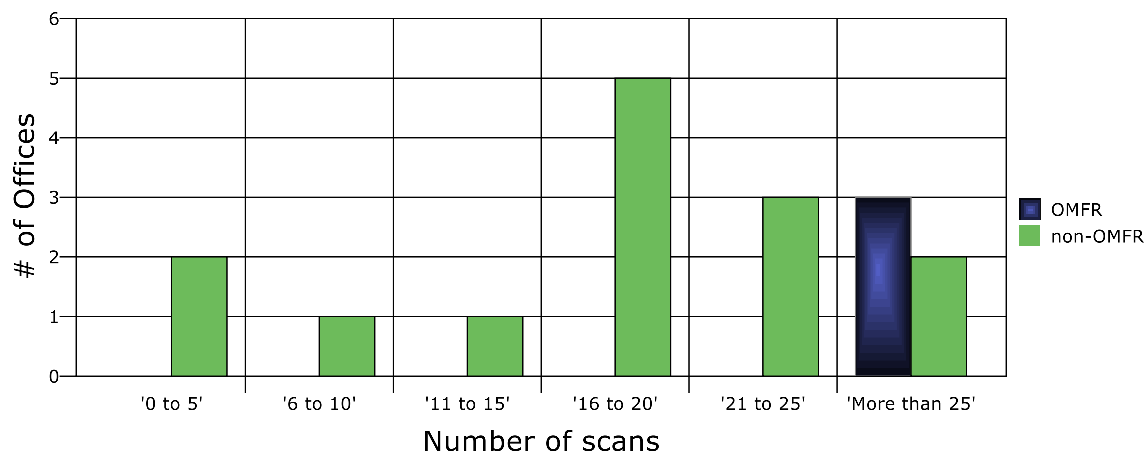


Figure 2. CBCT Scans per Month by OMFRs and non-OMFRs

Acceptance of outside referrals

All of the OMFRs reported accepting referrals for cone beam CT imaging while nine (64%) of the non-OMFRs reported accepting referrals from other dentists. As seen in Figure 3, all three OMFRs reported receiving ‘more than 10’ referrals per month which is the highest choice in the survey. Five (36%) of the non-OMFRs reported accepting ‘1 or 2’ referrals per month, 3 (21%) reported ‘3 to 5’ referrals per month and 1 (7%) reported accepting ‘more than 10’ referrals per month.

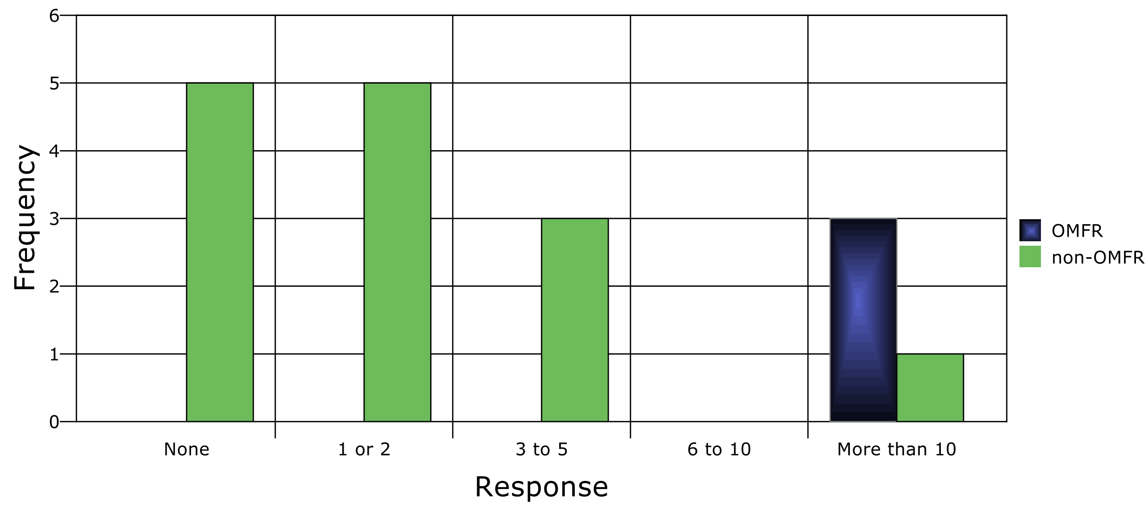


Figure 3. Outside referral scans per month

Scan acquisition

An important factor in image acquisition is the level of training of the person who exposes the images. Figure 4 shows the following: two of the OMFRs reported that radiologic technologists have primary responsibility for making CBCT exposures, while one OMFR reported having personal responsibility for making the exposures; ten (71%) of the non-OMFR practitioners reported that dental assistants have primary responsibility for making cone beam CT exposures while three (21%) reported that dental hygienists have primary responsibility and one (7%) non-OMFR reported personal responsibility for making cone beam CT exposures.

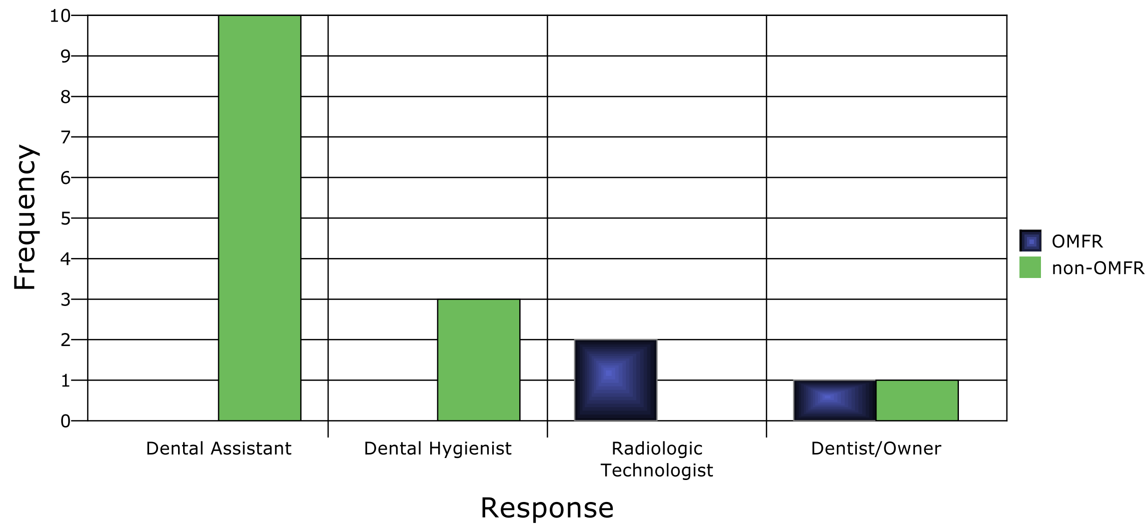


Figure 4. CBCT machine operator

Clinical uses for CBCT

This question asked the participants about six potential uses of CBCT in dental and maxillofacial imaging along with the frequency of use per day, week or month. Several interesting points are noted from the data presented in Figures 5 and 6. Both OMFRs and non-OMFRs reported using CBCT imaging for dental implant planning more than for any other area of dentistry. Another remarkable aspect of the reported uses for CBCT imaging is the differing response of OMFRs and non-OMFRs when asked about routine radiographs and replacement for panoramic imaging. None of the OMFRs reported using CBCT for routine radiographs or for panoramic replacements; however, four of the fourteen (29%) non-OMFRs reported using CBCT for routine radiographs ‘more than once per day’, one of the fourteen (7%) reported using CBCT for routine radiographs ‘on average, once per day’ and a total of eight of the fourteen (57%) non-OMFRs reported using CBCT for daily or occasional use for panoramic replacements.

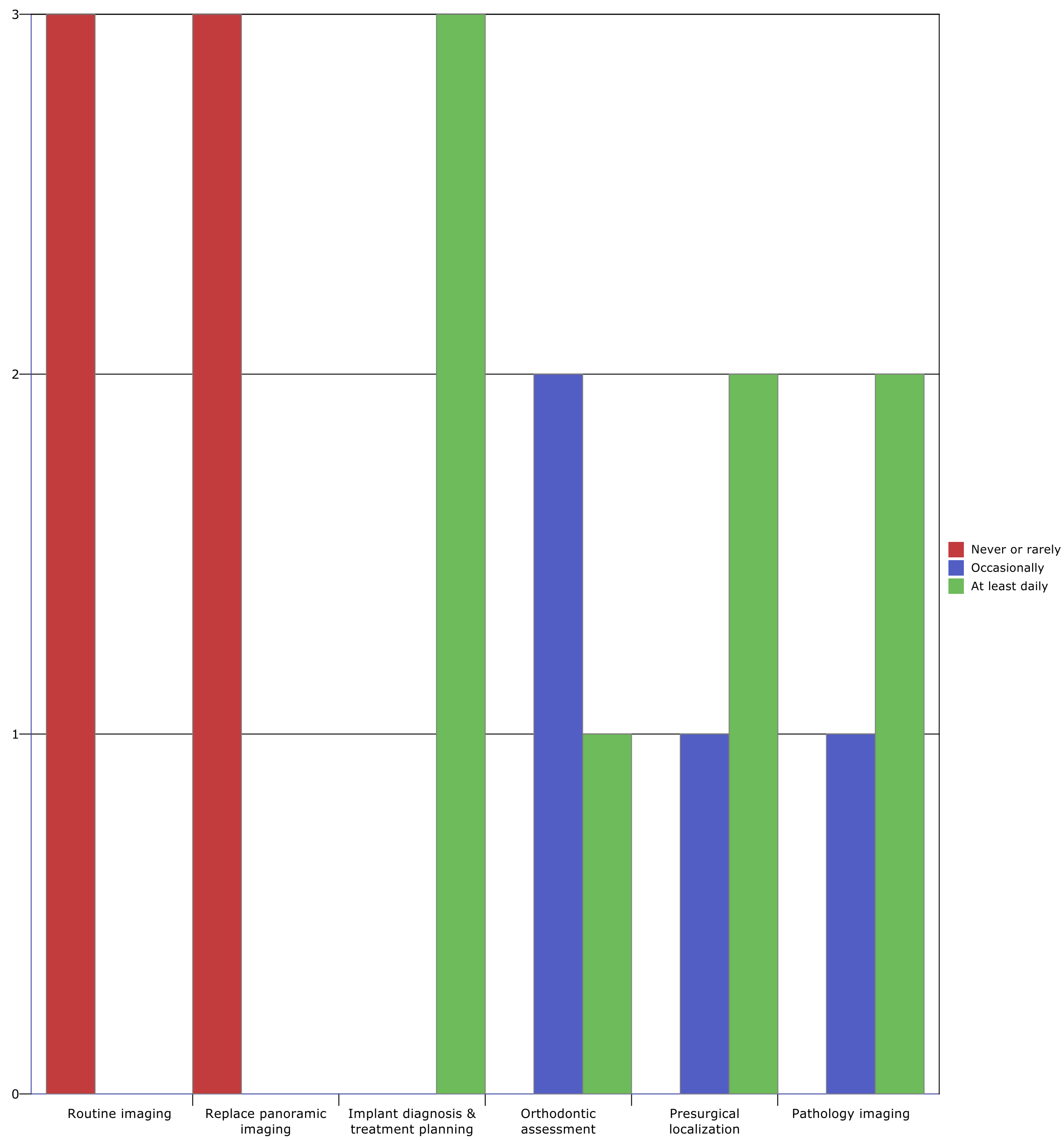


Figure 5. OMFR uses for CBCT imaging

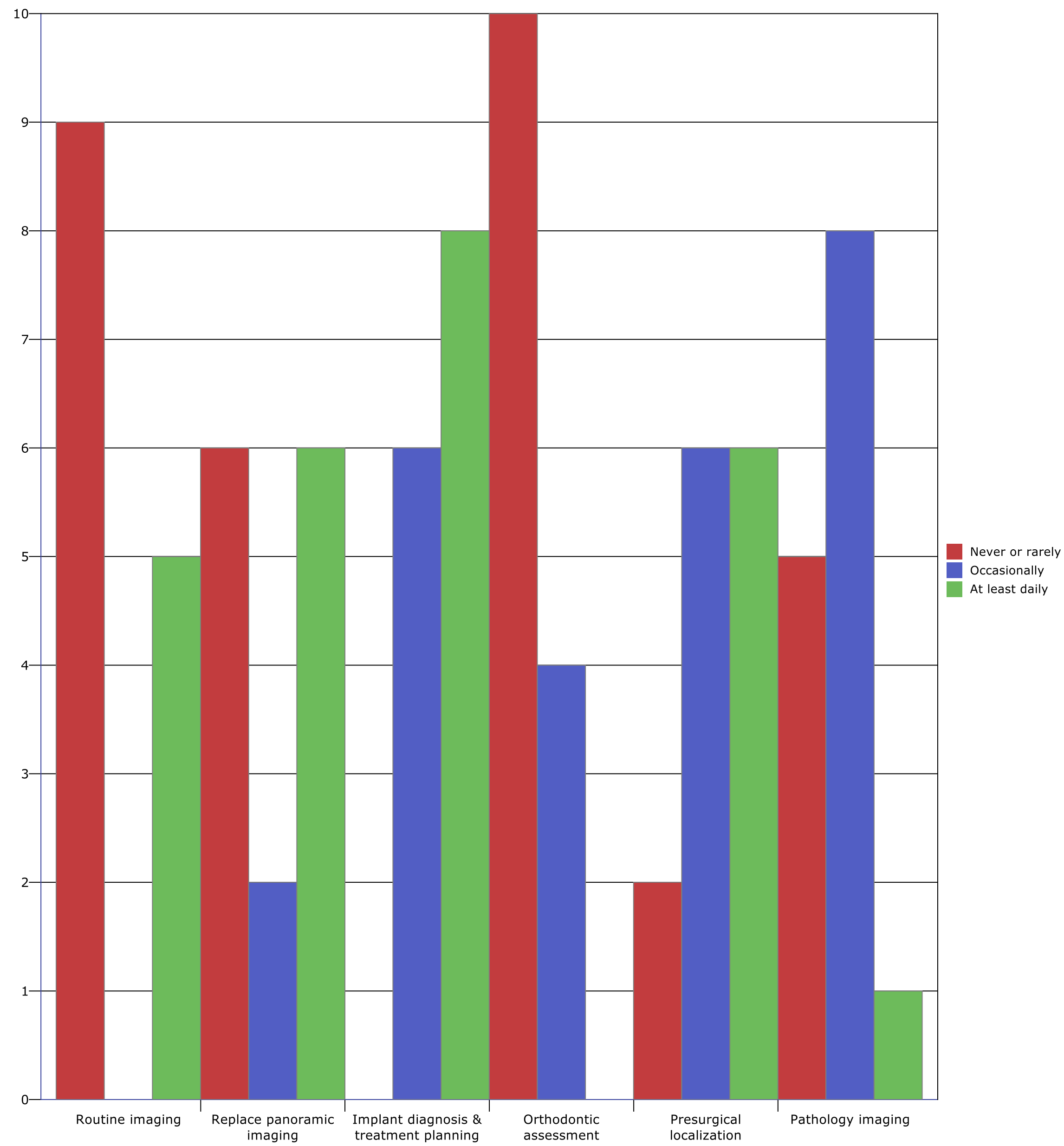


Figure 6. Non-OMFR uses for CBCT imaging

Interpretation of CBCT images

Another aspect in the office specific use of CBCT survey questions focused on who interprets CBCT images and how often non-OMFRs refer CBCT images to OMFRs for interpretation (Figure 7). The question asked 'Who primarily interprets your cone beam images for pathology?' Ten of the fourteen non-OMFRs reported that they interpret their own images while four reported that they refer their images to an OMFR for interpretation. The next question asked 'What percentage of your cone beam images do you refer to an Oral & Maxillofacial Radiologist for evaluation?'. Two (14%) of the non-OMFRs reported that none of their cone beam images are sent to an OMFR for evaluation while nine (64%) reported that '1 to 25%' of their cone beam images are referred to an OMFR; one non-OMFR (7%) reported that he referred '26 to 50%' and two non-OMFRs (14%) reported referring '100%' of their images to an OMFR.

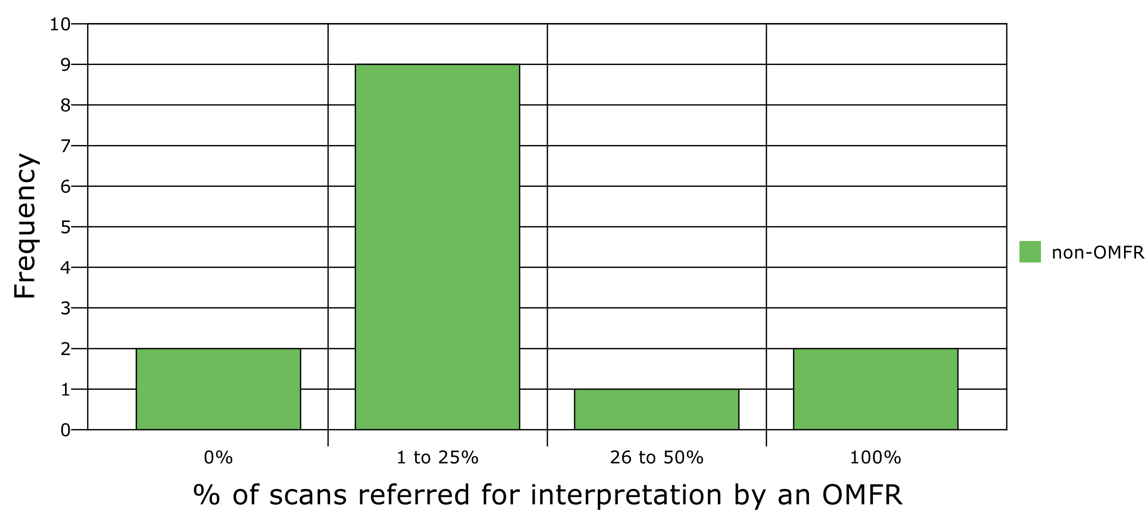


Figure 7. Frequency of OMFR referrals by non-OMFRs

The last question related to the interpretation report for cone beam images asked 'What is your office protocol for cone beam image reporting?' The three OMFRs reported that a full, separate imaging report in a standard manner is completed for all cone beam images. The non-OMFRs had more variable responses with half of the non-OFMRs incorporating the findings from CBCT images into other progress notes (Figure 8).

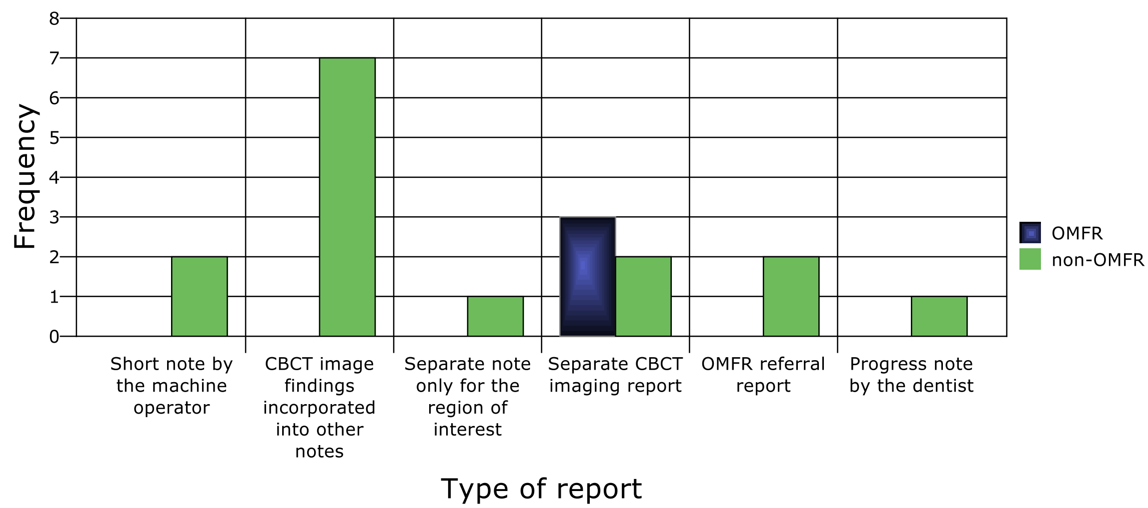


Figure 8. CBCT reporting

Technical Aspects of CBCT Imaging

The third category of questions related to the technical aspects of CBCT imaging and included questions about CBCT training, dosimetry and physics of dental cone beam radiology (Appendix A, question numbers 6, 8, 10 and 17 – 23).

CBCT training

Question #6 asked 'How many hours of training have you had in cone beam CT technology?' The answers to this question are found in Figure 9. The survey defined independent study as 'video, internet or other independent study'. Five of the eleven non-OMFRs answering this question reported no independent study as training for cone beam CT technology and four of the eleven reported ten or fewer hours of independent study. The total for these two groups indicates that nine of the eleven non-OMFRs (81%) reported ten or fewer hours of independent study in learning CBCT technology. The same pattern of responses was seen in the 'company sponsored seminar' category whereby five non-OMFRs reported that they did not attend a company sponsored seminar while four attended a seminar of ten hours or less in length. The major source of practitioner training in CBCT technology, as reported by the survey participants, is an 'in office company representative.'

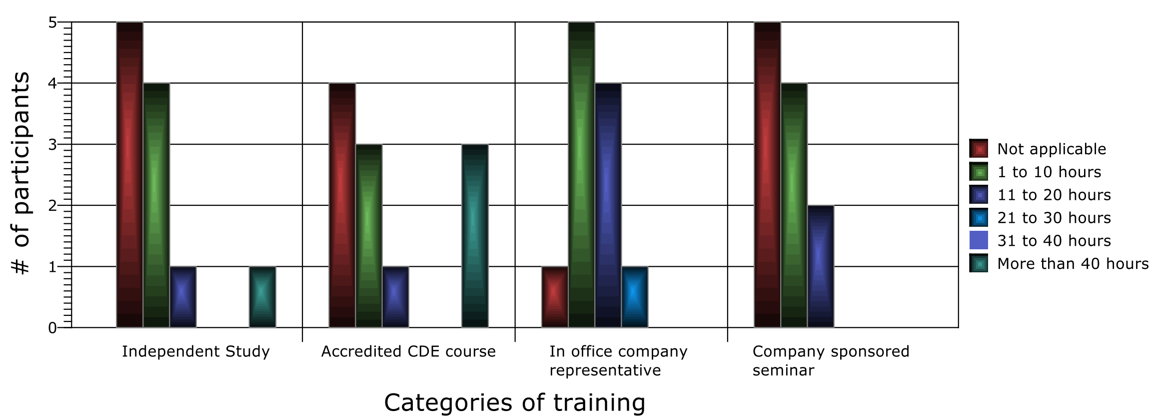


Figure 9. CBCT training for non-OMFR machine owners

The next subject in the technical training part of the survey related to the training of the person making the CBCT exposure. The OMFRs reported that the machine operators their offices are primarily professionally trained radiologic technologists who have in depth academic training in medical radiography, including plain diagnostic film and CT technology. Figure 10 shows that machine operators in the non-OMFR offices receive the majority of their training from 'in office company representatives' and very little from other sources such as independent study, accredited CDE or company sponsored seminars. For example, only two of the fourteen non-OMFRs who responded to this question reported that the machine operators in their offices attended a company sponsored training seminar of one or two hours in length; the remaining twelve machine operators did not attend a company sponsored seminar.

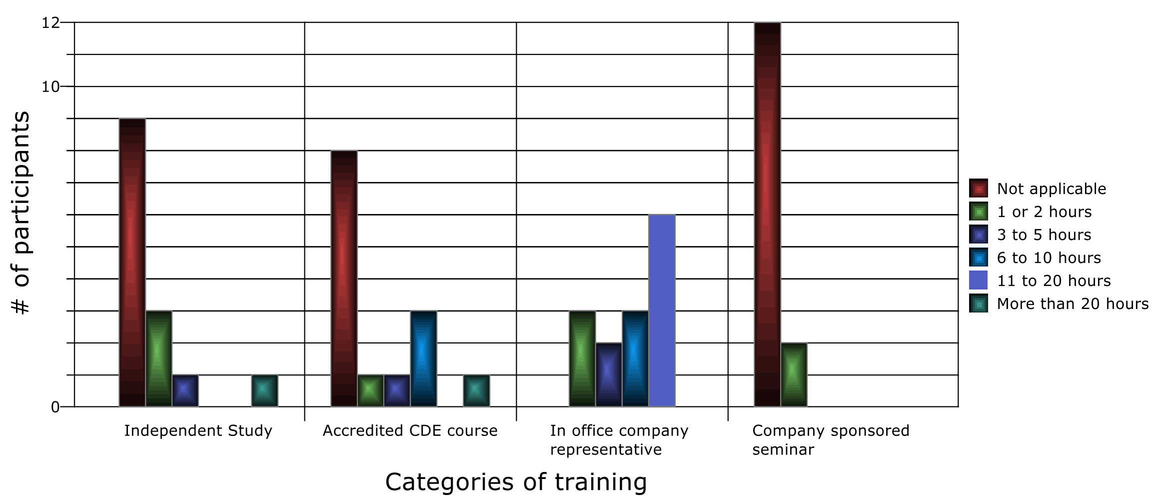


Figure 10. CBCT training for non-OMFR machine operators

Patient education and radiation dose

Patients ask questions about the radiation dose from CBCT scans. A reasonable method to explain effective radiation dose from CBCT exposures is to compare the numbers of other common radiology examinations or the number of days of background radiation exposure that will equal the radiation dose in one dental CBCT examination. In the survey, the participants were asked to use the maximum resolution and field of view settings for their particular machine. Figures 11 and 12 are graphs of the data from the OMFRs and non-OMFRs. The OMFRs answered the radiation dose equivalency questions with numerical choices as compared to the 'unsure' answers from the non-OMFRs. For example, the non-OMFRs answered 'unsure' 69% of the time when asked about the number of days of background exposure needed to equal one dental CBCT scan while one OMFR answered '3 days' and the other two OMFRs responded '10 days.' The only 'unsure' response for the OMFR respondent group was for the comparable number of full mouth series that would equate to one dental CBCT. In the non-OMFR group, nine of the thirteen respondents said 'unsure' as to the days of background radiation exposure that would equate to one dental CBCT exposure. Again, the OMFR respondents answered with actual number responses instead of the 'unsure' response as many non-OMFR respondents answered.

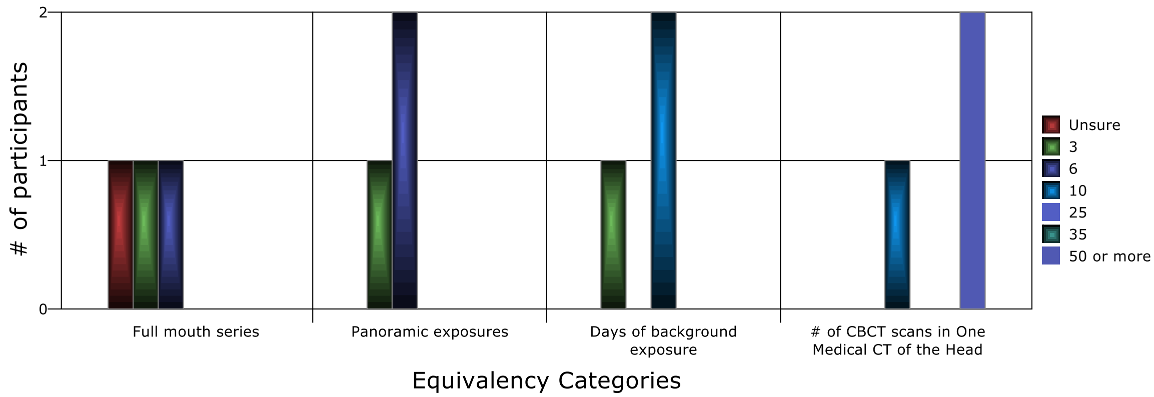


Figure 11. Radiation equivalencies for OMFR respondents

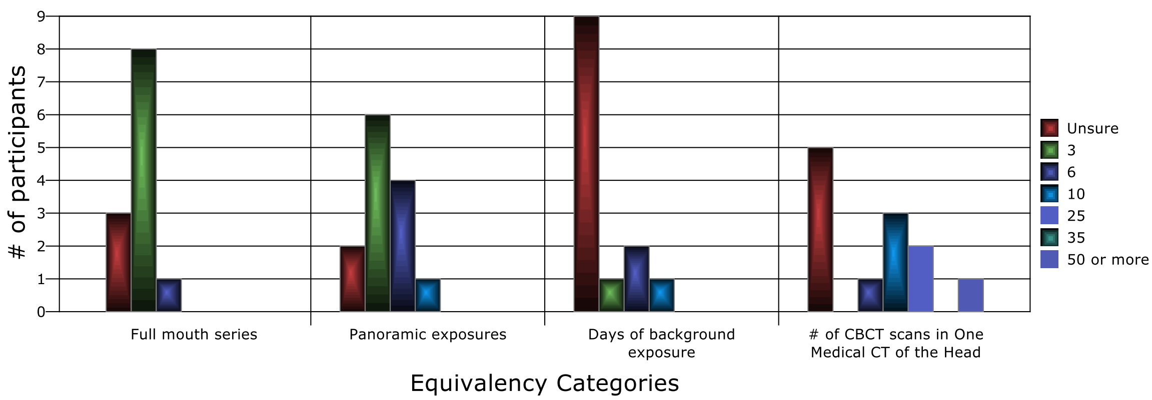


Figure 12. Radiation equivalencies for non-OMFR respondents

Ability to generate DICOM images

This series of questions concerned the importance and ability of CBCT machines to generate DICOM (Digital Imaging and Communications in Medicine) images and the ability of the clinician's viewing software to generate orthogonal and multiplanar views. All three OMFRs stated that the ability to generate DICOM images is 'very important,' while eight (57%) of fourteen of the non-OMFRs responded that the ability to generate DICOM images is 'very important,' three (21%)

responded that it is ‘moderately important’ and there were two non-OMFRs (14%) who did not answer this question (Figure 13).

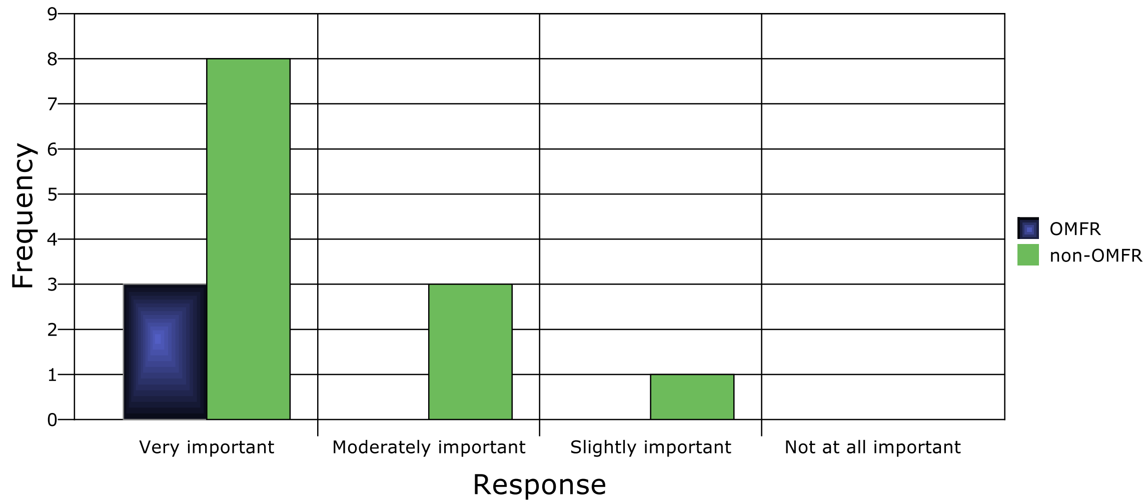


Figure 13. Importance of DICOM imaging

Use of orthogonal and multiplanar views

The next question was ‘Are you always able to obtain orthogonal views in your images?’ All three OMFRs responded yes while ten (71%) of the fourteen non-OMFRs answered yes, two (14%) stated no and two (14%) did not answer (Figure 14).

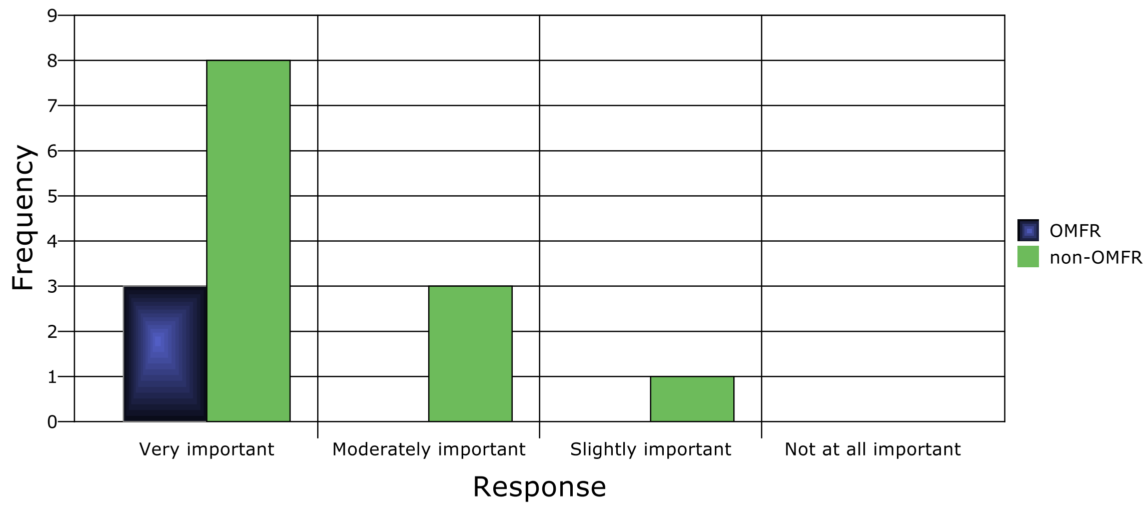


Figure 14. Ability to obtain orthogonal views

Next was the question, 'Do you use multiplanar reconstruction to examine your images?'. All three OMFRs responded yes while ten (71%) of the fourteen non-OMFRs answered yes, two (14%) stated no and two (14%) did not answer; the two who did not answer were not the same two who did not answer the previous question regarding orthogonal views (Figure 15).

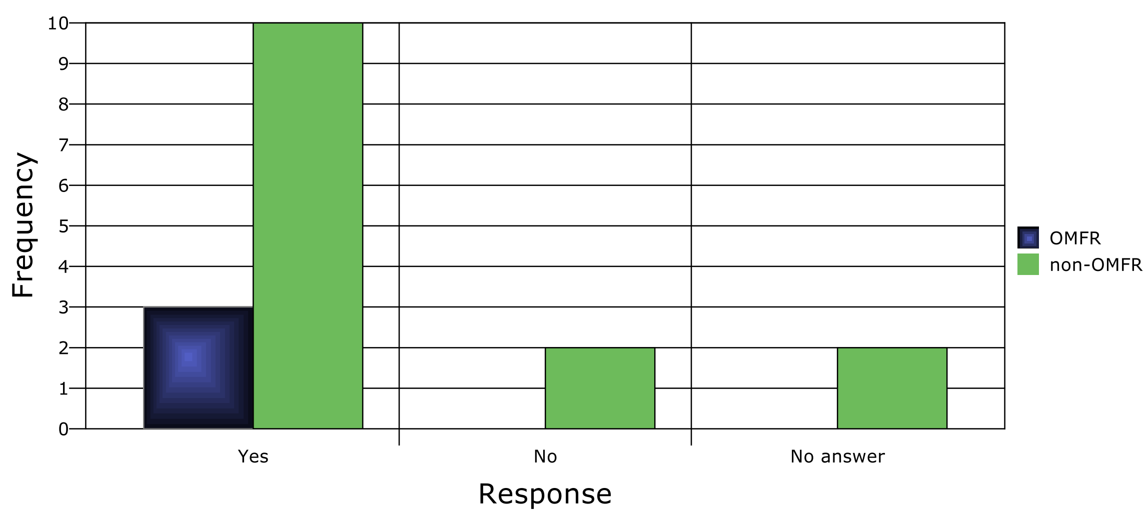


Figure 15. Use of multiplanar images

Estimating spatial resolution

This question asked the participants to estimate the spatial resolution of their CBCT machines. The answer choices were given in line pairs/mm (lp/mm) and included 0.5, 1.0, 2.0, 4.0, 10 and 15 lp/mm. Two OMFRs stated a spatial resolution of 2.0 lp/mm and one OMFR responded 4.0 lp/mm. Three non-OMFRs answered 0.5 lp/mm, two answered 1.0 lp/mm, five answered 2.0 lp/mm, two answered 4.0 lp/mm and two did not answer the question. The responses are shown in Figure 16.

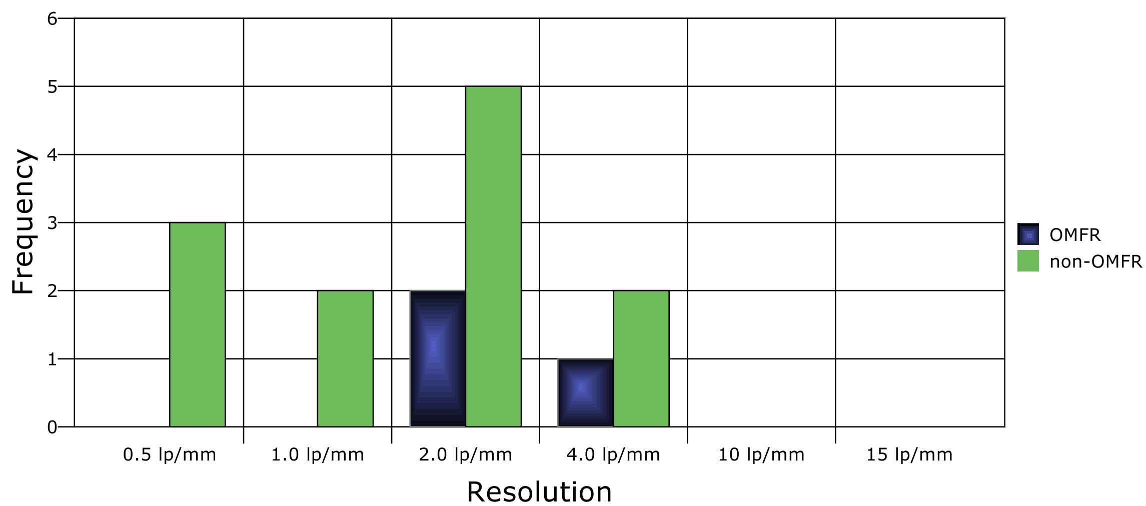


Figure 16. Estimated spatial resolution

Characteristics of CBCT machines

The following CBCT machine characteristics were listed as attributes and the participants were asked to rate their relative importance: high spatial resolution, high contrast resolution, short scan time capability, field of view (FOV) adjustment capability, use of image intensifier and use of flat panel detector. The respondents could choose the importance level of each characteristic as not important, slightly important, moderately important or very important. There was unanimous agreement among the OMFRs that high contrast resolution and FOV adjustment capability were both very important characteristics for CBCT machines to have (Figure 17). ‘Short scan time capability’ was the most highly rated machine characteristic by the non-OMFRs with eight (57%) of fourteen non-OMFRs selecting very important for this characteristic (Figure 18). Six (43%) of the non-OMFRs reported both high spatial and high contrast resolution as very important machine characteristics while three (21%) of the non-OMFRs responded that FOV adjustment capability is very important and three (21%) reported that FOV adjustment capability is not important.

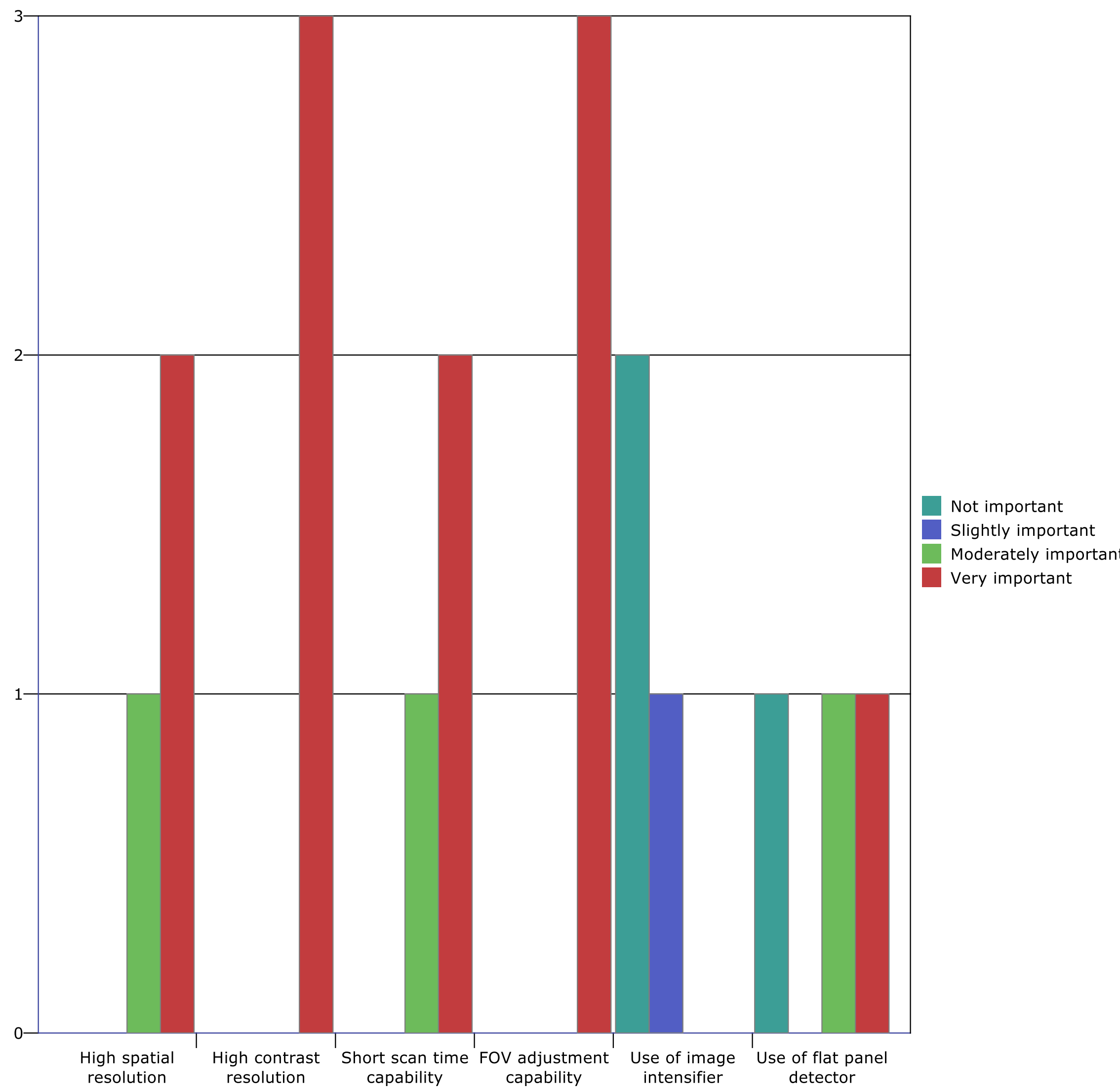


Figure 17. Preferred CBCT machine characteristics by OMFR response

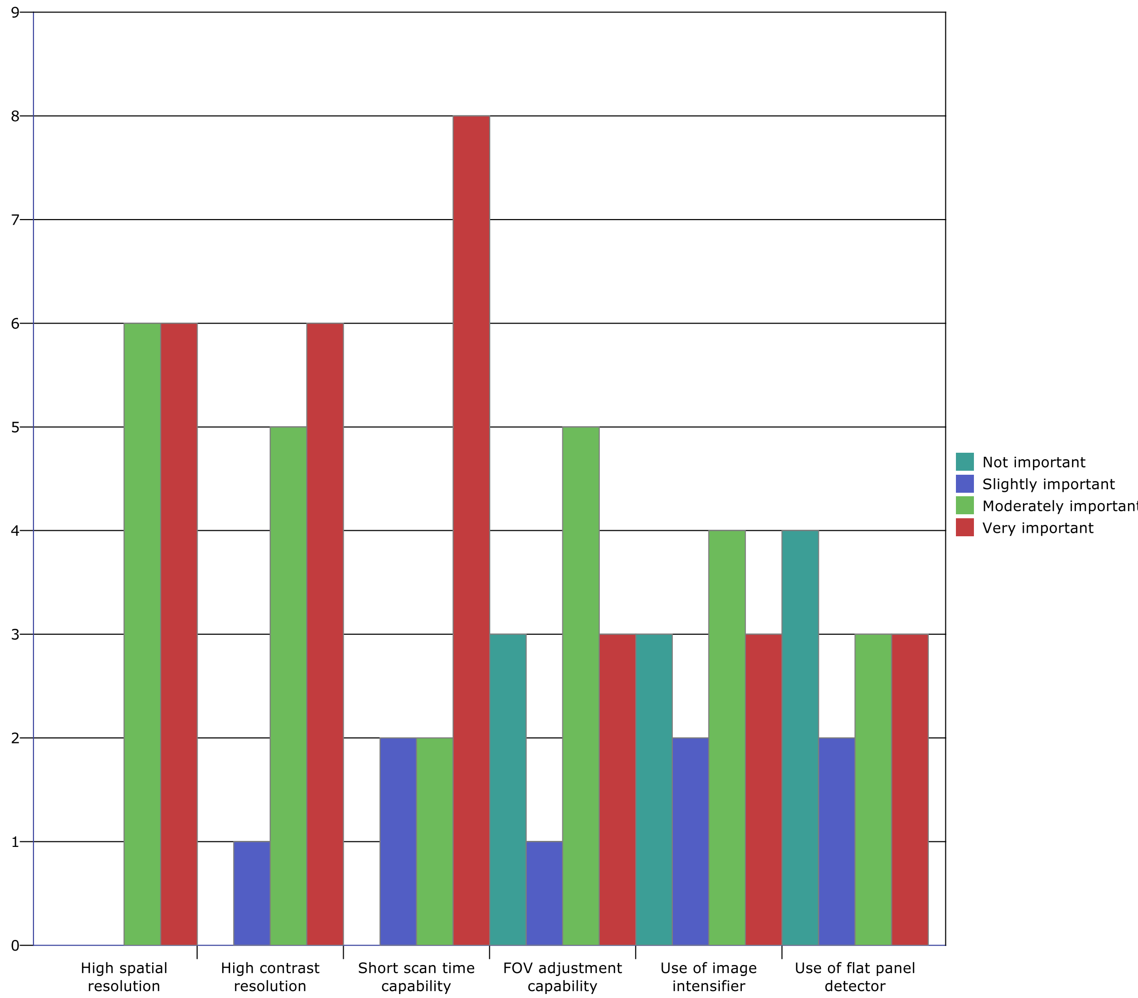


Figure 18. Preferred CBCT machine characteristics by non-OMFR response

Cause of poor image quality

The final question in this group of technical questions related to the cause of poor image quality. Choices for poor image quality were poor patient positioning; improper kVp, mA or exposure time selection; patient motion; mechanical failure; 'I never see image quality problems'; and other. All three OMFRs agreed that the main cause of poor image quality was patient motion. As seen in Figure 19, seven (50%) of the fourteen non-OMFRs responded that patient motion is the main cause of poor image quality while four (29%) answered poor patient positioning as the main cause of poor image quality and one (7%) responded ‘scatter from metal objects’ as the main cause of poor image quality.

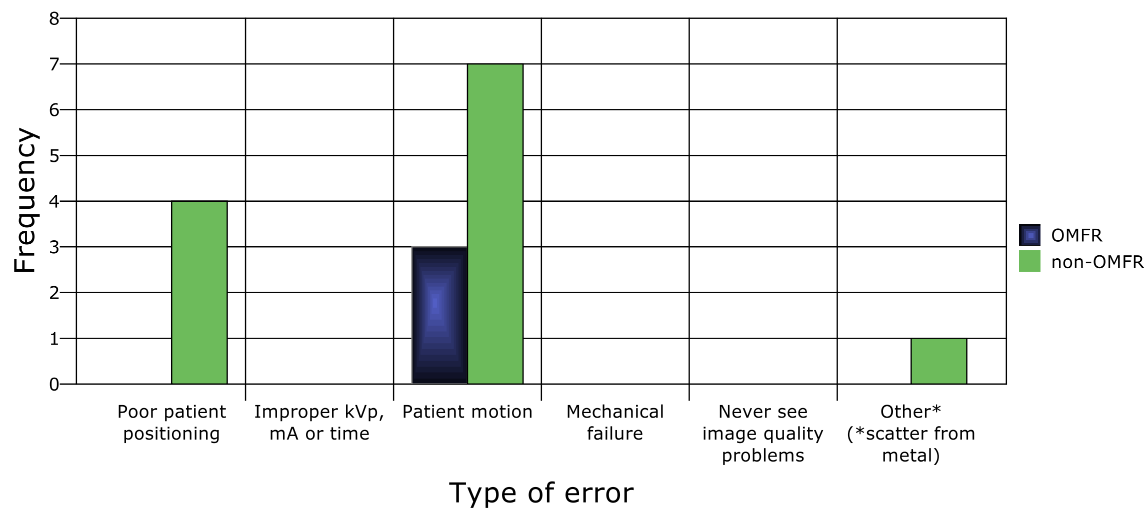


Figure 19. Causes of poor image quality

Interpretation Survey

The second online survey had a series of six questions for each of two anonymized cone beam CT image volumes. The first five questions for each volume were multiple choice questions that asked the identity of an anatomic feature or a pathologic condition; these questions were followed by an open-ended radiographic impression question. The purpose of this section of the survey was to determine the interpretation abilities of the non-OMFR participants as compared to the OMFR participants. Screen views from the survey are found in Appendix B beginning on page 60.

First volume

For the first volume (Jane Doe images), the three OMFRs were in unanimous agreement for the interpretation of the identified areas of anatomy, pathology or artifact for a cumulative score of 15 of 15 for 100%. The responses from the non-OMFRs were more varied. The answers to the first two questions were in unanimous agreement with the OMFRs. These questions asked about the identity of a deviated nasal septum and a retained root tip. The third question showed a partially bifid condyle; nine (82%) of the eleven non-OMFRs participating in the second part of the survey correctly identified this as a bifid condyle whereas two (18%) selected the 'normal condyle anatomy' choice. The fourth question referred to two images of the cervical spine, which showed an obvious subchondral cyst and an osteophyte, both signs of osteoarthritis of the cervical spine. Seven (64%) of the eleven non-OMFRs responded 'cervical spine osteoarthritis' while four (36%) responded 'macroglossia.' The fifth question for the first volume showed the most variation in the answers from the non-OMFRs. The correct answer was 'artifact' and three (27%) of the eleven non-OMFRs responded correctly. Four (36%) responded 'sella turcica,' three (27%) responded 'head positioner,' and one (9%) responded 'crista galli.' The non-OMFR cumulative score for the five multiple choice questions related to the first volume was 41 of 55 for 75%.

The sixth question was an open-ended question that asked 'What are your radiographic impressions for the Jane Doe case?' The OMFRs answered in a list or summary of findings such as this response: 'radiopaque foreign body in right maxillary molar region (also a possible retained root tip), edentulous max and mand.

Possible retained root tip in left maxilla canine/premolar region, degenerative arthritis in the right condyle, calcified thyroid cartilage.' Another OMFR response was '1 – Deviation of the nasal septum, 2 – Degenerative changes in the spine, 3 – Retained root tip.' The third OMFR response was more detailed: 'Review of the field of view demonstrates: 1. Tonsillar calcifications left and right of the oropharynx at the level of C2. 2. The right condyle is bifid in appearance. 3. Degenerative joint changes are associated with C-4 in the form of osteophytic formation on the anterior vertebral body. 4. Two regions of interest are noted in the maxilla—the regions of interest are objects of high attenuation, well defined, and nonuniform in shape. A differential diagnosis includes: osteosclerosis, particulate grafting material and retained root tips; because a periodontal ligament space is not noted surrounding the object of high attenuation, osteosclerosis is most likely. 5. An image artifact from the acquisition of data is noted throughout the volume.' The non-OMFR responses were more succinct in nature with six (55%) non-responses. Two of the five participants responding to this question provided one condition each. One responded 'moderate osteoarthritis' and the other single condition response was 'enough bone for implants.' The remaining three responses (27%) mentioned edentulism, alveolar ridge atrophy, retained root tips, bifid condyle, deviated septum, osteoporotic mandible, degenerative arthritis and calcified thyroid cartilage.

Second volume

The next six questions of the second survey were similar to the first six questions. The OMFRs were in almost perfect agreement. The only non-unanimous answer was for question ten. The screen view showed a dome-shaped soft tissue density along the floor of the left maxillary sinus associated with a periodontally involved second molar. Two of the three OMFRs agreed that this represented an area of 'localized sinusitis of odontogenic origin' while one OMFR answered that this was a 'mucous retention cyst.' The cumulative score for the OMFRs for this section of questions was 14 for 15 or 93%. The non-OMFRs showed a great deal of variation in the answers for this group of questions. The screen view for question seven referred to an irregular area of radiolucency in the right anterior maxilla that illustrated an area of osteomyelitis. Three (27%) of the non-OMFRs responded 'osteomyelitis' while four (36%) each responded 'fibrous healing defect' and 'incisive canal cyst.' Question eight referred to styloid processes. Eight (73%) of the non-OMFRs correctly answered this question while three (27%) answered 'calcified carotid atheromas.' Question nine showed an example of bilateral carotid atheromas. Five (45%) of the non-OMFRs answered this correctly while four (36%) responded 'tonsiliths' and two (18%) responded submandibular gland sialoliths. The tenth question referred to the soft tissue density within the left maxillary sinus. Seven (64%) of the non-OMFRs answered 'localized sinusitis of odontogenic origin', three (27%) answered 'mucous retention cyst' and one (9%) responded 'sinus polyp.' Question eleven had a screen view of multiplanar images of a normal TMJ including the normal concavity along the anterior surface, just inferior to the head of the condyle in the pterygoid fovea region. Eight (73%) of the non-OMFRs responded that this represented normal anatomy while two (18%) selected 'rheumatoid arthritis' and one (9%) answered 'subchondral cyst.' The non-OMFR cumulative score for the second volume was 31 for 55 or 56%.

Question twelve asked the overall impressions for the second volume. As in the first volume, there was some variation in the style of the OMFR responses. One responded ‘calcified carotid atheromas, localized osteomyelitis in the maxillary left canine region, localized left maxillary sinusitis of odontogenic etiology (periapical lesion), and some osteoarthritis of the cervical vertebra.’ Another OMFR response was ‘1 – A mucous retention cyst in the left maxillary sinus, 2 – Osteomyelitis on the right maxilla, 3 – Localized moderate/severe periodontitis on tooth #15, 4 – Bilateral carotid atheroma calcifications, and 5 – Degenerative changes in the spine.’ The third OMFR response was again more detailed: ‘Review of the field of view demonstrates: 1. Carotid calcifications left and right of the oropharynx at the level of C4, 2. The right anterior maxilla demonstrates a region of interest of an ill-defined irregular shaped region demonstrating a destructive inflammatory process indicative of osteomyelitis; a biopsy of this region is recommended to rule out a malignant process., 3. Severe periodontitis is associated with tooth #15; apical rarefying osteitis is associated with the mesiofacial root that extends to the inferior cortical border of the maxillary sinus., 4. Mucosal inflammation is associated with the left maxillary sinus along the inferior-lateral walls in the region of site #15., and 5. Mucosal thickening is associated with the maxillary right sinus.’ As with the first case, there were six (55%) non-responders in the non-OMFR group. One of the non-OMFR responses indicated a problem with the ability to clearly view the image and one of the responses was ‘nice quality.’ The remaining three non-OMFR responses mentioned the need for further evaluation of #7 with a differential diagnosis of incisive canal cyst or apical pathology requiring oral surgery referral, apical pathology associated with #14 which has resulted in the maxillary left sinus lesion, carotid calcifications, bilateral calcified stylohyoid ligaments, osteoarthritis of cervical vertebrae, periodontal disease and alveolar ridge atrophy.

Summary of interpretation results

The three OMFRs answered 10 multiple choice questions each for a total of 30 responses; they correctly answered 29 of 30 multiple choice identification questions for a 97% correct score. Eleven of the non-OMFRs answered the 10 multiple choice identification questions for a total of 110 responses; they correctly answered 72 of 110 questions for a 65% correct score. The radiographic impression questions and answers were more subjective due to the free form nature of the responses. The OMFRs all agreed on the impression answers except for the one opinion of mucous retention cyst instead of sinusitis of odontogenic origin. One of the OMFRs gave lengthy, detailed radiographic impression answers while the other two OMFRs gave succinct lists of radiographic impressions. Three of the non-OMFRs gave relatively well organized and short answers for the radiographic impression questions while the remaining eight either did not answer or gave short, incomplete answers.

Discussion

Based on the results of this pilot study with limited sample sizes, it appears that there are differences in how OMFRs and non-OMFRs use CBCT technology and in how they interpret cone beam images. Before discussing the actual findings of the study, a couple of observations about study design will explain the rationale for the type of survey that was chosen.

A major implementation barrier for surveys is the non-response rate. Acceptable non-response rates have been increasing in recent years for many reasons [18]; and, according to Groves, ‘there is no minimum response rate below which survey estimates are necessarily subject to bias.’ [19]. Nevertheless, as Groves also observes, maximizing survey response rates remains a worthwhile goal in modern survey practice. A well-recognized method for improving response rates while improving the accuracy and reliability of survey data is through the use of self-administered questionnaires. Respondents tend to be more honest, especially when asked about sensitive topics, when they are able to answer questions without an interviewer present [20]. As a result, computer-assisted interviewing is a mainstay of survey administration [21].

Internet and computer administration were the survey methods chosen in this study for several reasons. Consideration was given to visiting each office individually; however, as noted previously, self-administered questionnaires generally have higher response rates and are more accurate than interviewer-administered questionnaires. A closely related factor was the assumption that practitioners who had invested the time and finances in purchasing a CBCT machine would also tend to be more likely to embrace other computer technology such as e-mail, usage of the internet, digital radiology and CBCT viewing software; and, hence likely to participate in a survey utilizing web-based questionnaires.

This leads to the question of whether the choice of type of questionnaire affected response rates. Thirty-five CBCT machine owners were contacted and fifteen either did not respond or refused to participate. Perhaps a few of these practitioners were intimidated by the web-based survey and decided not to answer or simply refused to participate for some other reason. But, the obverse may be true—had in-person or paper surveys been used, the more technologically advanced practitioners may not have agreed to participate. Fourteen of the machine owners completed the surveys although four participants did not answer all of the questions on the second survey. In addition, there were six machine owners who initially agreed to participate but never began the first survey and did not respond to multiple follow-up contacts. These concerns all relate to the potential nonresponse bias introduced by the choice of the internet for questionnaire administration. It is tempting to assume that the more technologically oriented practitioners were attracted to the internet-based nature of the study; as a result, the study participants may have been practitioners who are more comfortable with computer technology in general and CBCT in particular, resulting in results that are biased towards more advanced users of CBCT technology. If paper questionnaires had been used, perhaps these more technically advanced practitioners would not have participated, thus yielding results unfavorable for the non-OMFR practitioners since more technologically oriented practitioners would not have been included in the study. In order to bring clarity to this question, an intensive post-survey follow-up study may have provided answers to question such as these [22]; however, due to the personnel, budget and time constraints of this project the follow-up study was not performed.

From the section of the results regarding demographics, a couple of interesting points are evident. First, the OMFRs and non-OMFRs graduated from dental school at similar times but their respective experience with CBCT technology varies considerably. Specialty trained OMFRs train for a minimum of two years in certificate granting programs and three years in masters degree programs. CBCT is a major part of the curriculum for these OMFR specialty programs as well as a major aspect of the practice of OMFR. All three of the OMFRs reported having greater than four years of experience, which is the longest time period as an option on the survey. Most of the non-OMFRs have two to four years of experience with CBCT technology. Also, nine of eleven (82%) of the non-OMFRs reported spending ten or fewer hours of independent study in the area of cone beam CT before purchasing a CBCT machine. The major source of non-OMFR practitioner training in CBCT was from in office visits by manufacturers' representatives. Even though the sample sizes are small, these noteworthy differences in how OMFRs and non-OMFRs learn about dental CBCT technology have the potential to contribute to significant differences in how CBCT technology is used and how images are interpreted.

We only have very basic demographic information regarding the non-OMFR trained CBCT machine owners who did not participate in the study. There were six (29%) general dentists in this group of twenty-one, while in the non-OMFRs who participated in the study, 50% were general dentists. In addition, 38% of the non-participating group were oral surgeons while in the group that participated in the study, 14% were oral surgeons. There was one orthodontist in the group that did not participate in the study while there were no orthodontists in the participating group. One prosthodontist was in each group. From this data, we can conclude that in our sample of non-OMFR trained CBCT machine owners, general dentists appear to be more likely to participate in the study than the oral surgeons; however, our sample sizes are too small to draw any statistically significant conclusions regarding participation bias. The percentage of participation versus non-participation was basically the same for both the periodontists and prosthodontists while there was only one orthodontist in the entire sample and she opted not to participate in the study.

One interesting indirect finding of the study related to the September 2009 Continuing Dental Education (CDE) CBCT course that was offered by the Oral & Maxillofacial Radiology faculty at the University of North Carolina School of Dentistry. Practitioners who were participating in this CBCT utilization study were offered a financial incentive of a one hundred dollar discount on the tuition for this course if they registered for the CDE course. No one in the study registered for the course. One can interpret this finding in several ways. Perhaps the time or place for the course was inconvenient for study participants. Perhaps the participants were looking for an advanced course whereas the CDE course was promoted as an introduction to CBCT technology. At any rate, there were no study participants who attended the CDE course even though a financial incentive was offered and the participants as a whole responded that they would be interested in a CDE experience in CBCT technology.

Another difference between OMFRs and non-OMFRs is the increased training of the staff person that acquires the cone beam images in OMFR facilities as compared to the non-OMFR practices. Radiologic technologists are professionals who have extensive training in many forms of diagnostic imaging, including plain film, CT and magnetic resonance imaging (MRI), that far exceeds the radiology training of dental auxiliaries. The results of the survey show that the OMFRs in this study utilize the services of more highly trained professionals to manage CBCT image acquisition than do the non-OMFRs in the study.

Important differences emerge when one looks at how OMFRs and non-OMFRs use their dental CBCT machines. None of the OMFRs use cone beam imaging as a routine radiographic examination but four out of fourteen (29%) of the non-OMFRs use cone beam imaging routinely. All radiographic examinations should be justified and should have an obvious benefit for the patient before being ordered and exposures made. Even though this is new technology, principles of optimization and justification apply to any radiological examination that uses ionizing radiation; in addition, as outlined in publications from the Food & Drug Administration (FDA), the National Council on Radiation Protection & Measurements (NCRP) and the

American Dental Association (ADA), routine radiographs are no longer accepted as part of modern radiological practice [7, 9, 23].

One area of questions relates to professional liability issues such as scanning patients of other dentists, referral of scans to an OMFR for interpretation and how radiographic reporting is accomplished for those scans that are not referred to an OMFR. In October 2008, The American Academy of Oral and Maxillofacial Radiology (AAOMR) offered an executive opinion statement on performing and interpreting diagnostic CBCT. This statement indicated that the practitioner obtaining the images has the responsibility to interpret the findings and to develop an imaging report [24]. In this CBCT interpretation study, all the OMFRs reported that a separate imaging report in a standard format is completed for all CBCT images while only two (14%) of the non-OMFRs complete a 'separate imaging report in a standard manner' and seven (50%) of the non-OMFRs state that 'cone beam findings are incorporated into other progress notes.' This study did not directly question participants on the issue of how the scans of outside patients are interpreted. The issue of how non-OMFRs manage outside referrals for CBCT imaging would be a good topic to include in future studies of the use of dental cone beam CT technology. Nine of fourteen (64%) non-OMFRs reported sending between 1 and 25% of their CBCT images to an OMFR for interpretation while two non-OMFRs reported not referring any images and two non-OMFRs reported referring 100% of their images to an OMFR and one non-OMFR reported referring between 26 and 50% of his images. These responses indicate that as a group, the non-OMFRs in this study referred a small percentage (approximately 25%) of all their CBCT scans to OMFRs for interpretation. There is no existing data that indicate the numbers or percentages of CBCT scans that non-OMFRs refer to OMFRs for interpretation. As the 2008 AAOMR executive opinion states, ‘dentists using CBCT should be held to the same standards as board-certified oral and maxillofacial radiologists (OMFRs), just as dentists excising oral and maxillofacial lesions are held to the same standards as OMF surgeons’ [24]. The issue of referral patterns of non-OMFRs requires further study as the use of cone beam CT technology becomes more widely adopted in dentistry.

Another difference between OMFRs and non-OMFRs was in the dosimetry equivalencies and patient education section. The question asked the participants to use the highest resolution and dosage settings for their particular machines, and as such, variation in the answers was expected since there are different machines used by practitioners in the study. The ‘unsure’ answer by the non-OMFRs is remarkable since a common method to describe the radiation dose in radiographic examinations is to compare the amount of radiation in one exposure to the amount of background radiation a person is exposed to in daily life [5, 7, 23]. Practitioners who are responsible for ordering, exposing and interpreting radiographs must know the effective radiation dose that is used to generate the radiograph. This is basic knowledge that is required when the practitioner is making the risk to benefit analysis for the patient and deciding whether to order the examination [5, 25, 26]. If the practitioner does not know the amount of radiation being used for the radiographic examination, the risk of the examination can not be properly determined; and, if the risk can not be determined, then the risk to benefit analysis can not be properly accounted for and the patient should not be subjected to the radiographic examination. The patient's right to informed consent for the radiographic examination is jeopardized if the risks and benefits are not fully expressed by the practitioner or staff member exposing the radiograph [27].

The next set of questions related to the value that the participants placed on their imaging systems to provide DICOM images with orthogonal and multiplanar reconstruction abilities. All of the OMFRs rated the ability to provide images in DICOM format as very important while only eight of fourteen (57%) of the non-OMFRs rated DICOM images as very important. All of the OMFRs responded that they are able to obtain orthogonal views and that they use multiplanar images when examining CBCT volumes while only ten (71%) of the non-OMFRs responded that they can obtain orthogonal views and that they use multiplanar images when examining CBCT volumes. These differences illustrate a low level of understanding or appreciation for the basic advantages of computed tomography images by four (29%) of the non-OMFRs. All practitioners using computed tomography should know the importance of adhering to the DICOM standard. Among many other benefits such as patient and imaging data, the DICOM format standardizes CBCT images across different platforms from different manufacturers. Orthogonal views enable the practitioner to view the area of interest at a ninety degree angle to the bone surface or panoramic curve as drawn by the practitioner. This is a necessary component of the viewing software in order to develop reliable measurements of bony landmarks. Multiplanar views are vital when evaluating volumes in the axial, coronal and sagittal planes. Trained OMFRs know and appreciate these basic imaging tools. Many of the non-OMFRs in this study do not appear to understand or to utilize these basic CBCT imaging features.

The next question asked about spatial resolution of CBCT machines. Perhaps the most direct method used to estimate the highest spatial resolution that the machine is capable of is by using the smallest pixel size available in the system and then convert this value to line pairs per mm (lp/mm). For example, pixel sizes of 0.5 mm will result in a maximum of 1 lp/mm since two pixels are required to visualize one line pair. As expected, a range of values was selected. Two of the OMFRs answered 2.0 lp/mm and one OMFR responded 4.0 lp/mm. Two non-OMFRs also answered 4.0 lp/mm, which would equal pixel sizes of 0.125 mm in order to have eight pixels per mm to yield the reported 4 lp/mm. One of the non-OMFRs and one of the OMFRs own the Gendex machine. The manufacturer states that the resolution in line pairs is 14 lp/cm at .2 voxel scan [28]. This value is confusing since 14 lp/cm equals 1.4 lp/mm which equals 2.8 pixels /mm or .36 mm pixel size. The manufacturer also states that 0.125 mm pixel sizes are available in small volume imaging; this is the equivalent of 4 lp/mm spatial resolution, so it is possible that the Gendex machine could yield the 4 lp/mm spatial resolution as reported. Per Farman et al, the Planmeca unit has a 0.18 mm isotropic voxel [29] which results in 5.6 pixels per mm or 2.8 lp/mm spatial resolution; this unit does not appear to be capable of reaching 4 lp/mm spatial resolution. Imaging Sciences International reports that the smallest voxel size for the iCAT Next Generation is 0.12 mm which yields 4 lp/mm [30, 31]. The most interesting responses for this question appear to be the one 4 lp/mm non-OMFR response that can not be determined from the Planmeca machine and the two nonresponses from the non-OMFRs. One interpretation of the nonresponses is that the participants were either unsure of their machine's spatial resolution or were not familiar with the relationship of spatial resolution and line pairs/mm. Spatial resolution is widely used in the marketing of CBCT machines; in order to make informed decisions for purchasing and using cone beam CT machines, all practitioners who own or operate these machines should have a working knowledge of pixel and voxel size and how these relate to line pairs/mm and spatial resolution. These non-responses appear to indicate a lack of understanding of this subject.

CBCT machine characteristics were addressed in the next section of questions. The OMFRs unanimously agreed that high contrast resolution and capability of FOV adjustment were very important features for dental CBCT machines. The non-OMFRs disagreed with the OMFRs regarding the importance of high contrast resolution and FOV adjustment since only three (21%) of the non-OMFRs stated that high contrast resolution and capability for FOV adjustment are important. These findings seem to indicate a lack of understanding of the imaging physics of CBCT. The reason that CBCT has good ability to distinguish bone edges and borders relates to properties of contrast; without good contrast resolution, CBCT would be a much less useful imaging modality. Using the proper field of view is a vital feature of all radiographic procedures whether they are routine two-dimensional imaging procedures or more advanced three-dimensional imaging techniques. Most dental x-ray machines have pre-set fields of view and do not offer adjustment capability, with the exception of using rectangular collimators with round tubes for intraoral imaging. The increased radiation dosage that patients receive in CBCT mandates that appropriate collimation be used and that CBCT machines have the capability of FOV adjustment in order to limit radiation exposure to only the region of interest as set forth in the ALARA (As Low As Reasonably Achievable) principle[32, 33]. These results seem to show that many of the non-OMFRs in this study do not appreciate the importance of using the ALARA principle to limit radiation dosage when using CBCT technology.

The final question in the first online survey asked about the cause of poor image quality. All three OMFRs agreed that the primary reason for poor image quality is patient motion while only seven of the fourteen (50%) non-OMFRs indicated that patient motion is the cause of poor image quality. Also, eight of fourteen (57%) of the non-OMFRs reported that short scan times were very important. This seems to illustrate that approximately half of the non-OMFRs understand the relationship between scanning time and patient motion; it is well-accepted that the longer a scan takes, the more likely there will be patient motion. It is also interesting to note that four (29%) of the non-OMFRs indicated that poor patient positioning was the primary reason for poor image quality while one (7%) indicated that 'scatter from metal objects' was the reason for poor image quality. These results appear to illustrate the inadequate training of the staff member who is making the exposures. Poor image quality due to patient positioning errors can be corrected with proper education and training of the person making the exposures. Patient motion can be minimized with good patient education and proper patient stabilization; however, instances of involuntary patient motion may still occur and remains the primary cause of poor image quality even with optimal imaging protocols.

The second section of the study was the interpretation exercise. As described previously, the OMFRs answered 29 of 30 (97%) multiple choice questions correctly while the non-OMFRs answered 72 of 110 (65%) multiple choice questions correctly. Due to the small sample sizes in this study, inferential statistical analysis is not indicated; however it is notable that the OMFRs were in almost perfect agreement while the non-OMFRs scored poorly on the multiple choice interpretation questions. This study does not prove that the interpretation skills of non-OMFRs are not as good as the interpretation skills of OMFRs; but, it is apparent that in this particular sample of OMFRs and non-OMFRs, the OMFRs performed extremely well at interpreting these CBCT images and the non-OMFRs performed in a substandard manner. Another very notable finding in the interpretation section is again the almost perfect agreement in the 'radiographic impression' section for the OMFRs while only three out of eleven (27%) of the non-OMFRs answered in a well organized and comprehensive manner. This finding again highlights the differences in the interpretation skills of the OMFRs and non-OMFRs in this study.

In light of the fact that approximately 25% of the CBCT scans taken by non-OMFRs in this study are referred to OMFRs for interpretation, the 65% score on the interpretation exercise brings to mind the following potential scenario. Non-OMFRs erroneously identified 35% of the anatomical and pathological conditions found on the CBCT screenshots in this study while referring approximately 25% of the scans taken. This means that if each of the scans made by non-OMFRs have one finding each, three-fourths of the scans made by non-OMFRs will have a 35% interpretation error rate, on average. This leads to an interpretation error in approximately 25% of the scans taken by non-OMFRs (.75 of scans taken multiplied by a .35 error rate = .2625 total error rate, or ~25% scan interpretation error rate). Based on the referral pattern reported by the non-OMFRs in conjunction with the interpretation exercise in this study, 50% of the CBCT scans taken by non-OMFRs are interpreted correctly while 25% of the scans taken by non-OMFRs are referred to OMFRs for interpretation and 25% of the scans have interpretation errors. Of course it must be re-emphasized that this scenario is limited to the small group of non-OMFRs in this study and may not be valid if extrapolated to the larger population of all non-OMFRs who are using dental CBCT.

One of the dosage equivalency questions turned out to be a source of confusion for the participants. The question asked the participants to relate CBCT radiation dosage to the radiation dosage of a FMX. There is a considerable range of radiation dosages from FMXs depending on whether the x-ray beam was collimated with a round cone or a rectangular collimator as well as the type of receptor used [5]. This issue of how to arrive at an estimation of effective doses depending on the technique of the FMX most likely contributed to some degree of uncertainty on the part of the study participants as they considered how FMX effective radiation doses compared to dental CBCT effective radiation doses. This effective dose comparison should be defined more precisely if this question is used in future studies.

Conclusions

It is evident that the OMFRs and non-OMFRs in this study use CBCT technology differently. In this study, the OMFRs have more training and more experience in the use of CBCT technology than the non-OMFRs. OMFRs use their training and experience to avoid the routine use of CBCT imaging, instead using more stringent patient selection criteria than the non-OMFRs. The OMFRs in this study are better equipped to discuss comparative radiation dose equivalency with their patients than are the non-OMFRs. As evidenced by the importance given to field of view adjustment features on CBCT machines and the use of patient selection criteria, the OMFRs in this study adhere more closely to the principles of ALARA than do the non-OMFRs in this study. And, finally, the OMFRs in this study performed almost perfectly in the interpretation exercise while the non-OMFRs scored below 70% on the recognition of basic anatomic and pathologic features.

Due to the limited sample sizes in this study, it is not possible to make comparative statements about all OMFRs and all non-OMFRs; however, we can state that in this study, the OMFRs used CBCT technology in a more reliable and clinically effective manner than did the non-OMFRs. Further study of how dentists are using CBCT in their practices is required to increase our understanding of this rapidly changing aspect of dental practice.

Appendix A

Screen views from Part 1 of the survey

1) Please indicate how long you have used cone beam CT technology. The machine used for scanning could be either in your practice or owned by someone else.

0 to 6 months ▾

2) Please indicate how long your practice has owned a cone beam CT machine. If your practice does not own a cone beam CT machine, please select N/A.

0 to 6 months ▾

3) In the following list, please select the manufacturer and model of the cone beam CT machine used in your practice. If not listed, please enter in the 'other' category.

- ○ iCAT Classic
- ○ iCAT Next Generation
- ○ Kodak 9500
- ○ NewTom 3G
- ○ NewTom VG
- ○ Planmeca
- ○ Sirona Galileos Comfort
- ○ Sirona Galileos Compact
- ○ Other

4) What viewing software do you normally use to view your cone beam CT volumes?

5) On average, how many cone beam scans does your office make per month?

- 0 to 5
- 6 to 10
- 11 to 15
- 16 to 20
- 21 to 25
- More than 25

6) How many hours of training have you had in cone beam CT technology?

	N/A	1 to 10 hours	11 to 20 hours	21 to 30 hours	31 to 40 hours	More than 40 hours
Video, internet or other independent study						
Accredited CDE course						
In office company representative						
Company sponsored seminar						

7) Who is primarily responsible for cone beam image acquisition in your practice? If you specify 'other,' please list the specific title of the operator.

- Dental Assistant
- Dental Hygienist
- Radiologic Technologist
- Self (Dentist/owner)
- Other

8) How many hours of cone beam CT training has the primary machine operator in your office received?

	N/A	1 or 2 hours	3 to 5 hours	6 to 10 hours	11 to 20 hours	More than 20 hours
Video, internet or other independent study	○	○	○	○	○	○
Accredited CDE course	○	○	○	○	○	○
In office company representative	○	○	○	○	○	○
Company sponsored seminar	○	○	○	○	○	○

9) Who is secondarily responsible for cone beam image acquisition in your practice? If you specify 'other,' please list the specific title of the operator.

○ N/A

○ Dental Assistant

○ Dental Hygienist

○ Radiologic Technologist

○ Self (Dentist/owner)

○ Other

If **N/A** Is **Selected**, Then Skip To **11) The following is a list of potent...** Edit

10) How many hours of cone beam CT training has the secondary machine operator in your office received?

	N/A	1 or 2 hours	3 to 5 hours	6 to 10 hours	11 to 20 hours	More than 20 hours
Video, internet or other independent study	○	○	○	○	○	○
Accredited CDE course	○	○	○	○	○	○
In office company representative	○	○	○	○	○	○
Company sponsored seminar	○	○	○	○	○	○

11) The following is a list of potential uses of cone beam CT imaging in dentistry. In the spaces provided, please indicate the frequency your cone beam CT machine is used for each purpose listed.

	More than once per day	On average, once per day	A few times per week	A few times per month	Rarely	Never
Routine radiographic examination	○	○	○	○	○	○
Replacement for panoramic imaging	○	○	○	○	○	○
Implant diagnosis and/or treatment planning	○	○	○	○	○	○
Orthodontic or growth and development assessment	○	○	○	○	○	○
Pre-surgical localization; e.g., for the mandibular canal or maxillary sinus	○	○	○	○	○	○
Additional imaging for pathology to supplement 2D imaging	○	○	○	○	○	○

12) Who primarily interprets your cone beam images for pathology? If you have someone not listed to read your images, please select 'other' and specify who reads your images.

- Self
- Oral Surgeon
- Oral & Maxillofacial Radiologist
- Medical Radiologist
- Oral Pathologist
- Other ______

13) What percentage of your cone beam images do you refer to an Oral & Maxillofacial Radiologist for evaluation?

- 0%
- 1 to 25%
- 26 to 50%
- 51 to 75%
- 76 to 99%
- 100%

14) Do other dentists refer patients to your office for cone beam imaging?

- Yes
- No

If **No** Is **Selected**, Then Skip To **16) What is your office protocol for...** Edit

15) Please estimate how many cone beam scans your office performs per month for other dentists.

- 1 or 2
- 3 to 5
- 6 to 10
- More than 10

16) What is your office protocol for cone beam image reporting? Please select the most appropriate response; if 'other,' please describe how you report your cone beam image findings.

- Short progress note by the machine operator only
- Cone beam image findings are incorporated into other progress notes
- Separate progress note entry that describes the region of interest
- Separate imaging report in a standard manner for all cone beam images
- Other

17) Regarding patient education, patients may ask about how much radiation they receive during a cone beam CT scan in your office. How would you respond to the following questions? Assume that you are using the maximum FOV and highest resolution on your cone beam machine.

	Unsure	3	6	10	25	35	50 or more
How many full mouth series does this scan equal?	○	○	○	○	○	○	○
How many panoramic exposures does this scan equal?	○	○	○	○	○	○	○
How many days of background radiation am I getting with this scan?	○	○	○	○	○	○	○
How many of these scans equals a head CT in the hospital?	○	○	○	○	○	○	○

18) How important is the ability of your machine to generate DICOM images?

Not at all important ▾

19) Are you always able to obtain orthogonal views in your images?

Yes ▾

20) Do you use multiplanar reconstruction to examine your images?

Yes ▾

21) What would you estimate the spatial resolution of your unit to be?

0.5 lp/mm ▾

22) Please rate the relative importance of the following cone beam CT machine characteristics.

	Not Important	Slightly Important	Moderately Important	Very Important
High spatial resolution	○	○	○	○
High contrast resolution	○	○	○	○
Capability to have short scan times	○	○	○	○
Capability for FOV adjustments	○	○	○	○
Image capture with an image intensifier	○	○	○	○
Image capture with a flat panel screen	○	○	○	○

23) In your experience, what is the main cause of poor cone beam CT image quality?

- ○ Poor patient positioning
- ○ Improper kVp, mA or exposure time selection
- ○ Patient motion
- ○ Mechanical failure
- ○ I never see image quality problems
- ○ Other

24) What year did you graduate from dental school? If you completed a specialty program, please indicate your specialty and year of completion for your post-graduate program as well.

25) How would you characterize your practice? If you select 'other' please indicate your type of practice. You may select more than one practice type.

- ☐ General or Family Practice
- ☐ General Practice with an emphasis on Cosmetic Dentistry
- ☐ General Practice with an emphasis on Adult Restorative Dentistry
- ☐ Orthodontic Practice
- ☐ Oral & Maxillofacial Surgery Practice
- ☐ Oral & Maxillofacial Radiology Practice
- ☐ Periodontic Practice
- ☐ Endodontic Practice
- ☐ Pediatric Dental Practice
- ☐ Prosthodontic Practice
- ☐ Educational or Academic Institution
- ☐ Other

26) Would you attend continuing dental education in cone beam CT imaging at the UNC School of Dentistry, if it were made available?

- Yes
- No

If No Is Selected, Then Skip To Thank you very much for your time and... Edit

27) What is the length of time you would prefer for a CDE course on cone beam CT imaging?

3 hours

28) What specific topics would you recommend for a course in cone beam CT imaging?

Thank you very much for your time and cooperation in completing this survey. Your participation in this study will enhance future cone beam CT education as well as improve patient diagnoses, treatment and outcomes.

When you have reviewed the two cone beam volumes, proceed to the second part of the survey!

The link to the first online survey is: http://uncodum.qualtrics.com/SE?SID=SV_1Hz5DTn4s5uKtOQ&SVID=Prod.

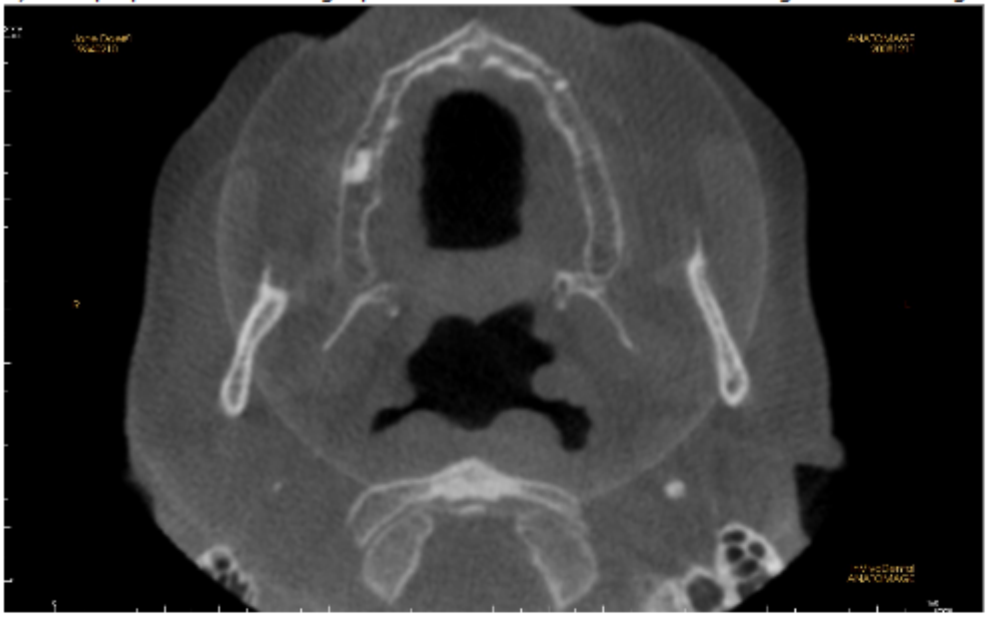
Appendix B

Screen views from Part 2 of the survey

1) The following Jane Doe image most likely represents:

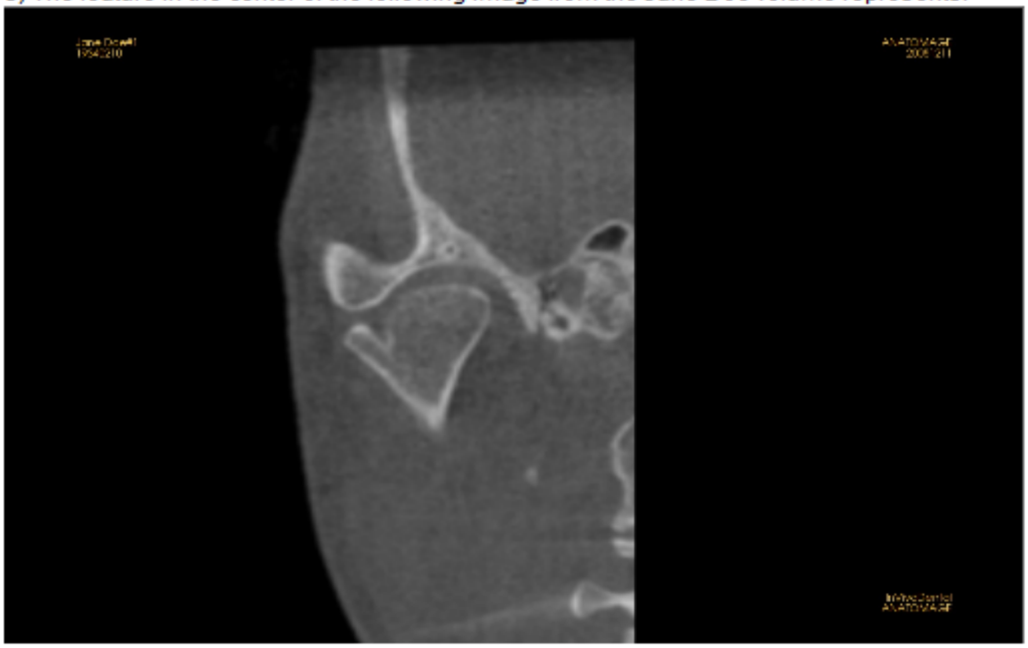
- pneumatized maxillary sinus
- deviated nasal septum
- fractured left zygomatic arch
- concha bullosa

2) The opaque mass in the right posterior maxilla shown in the following Jane Doe image is likely to represent:



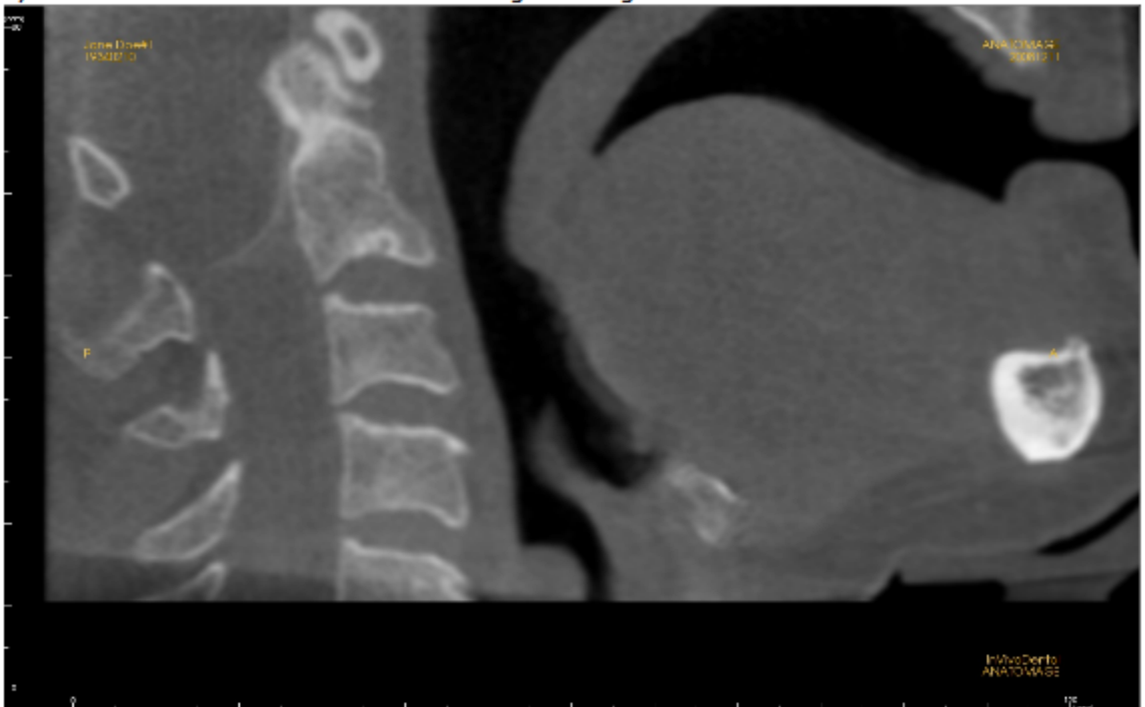
- palatal torus
- pneumatized maxillary sinus
- root tip
- residual cyst

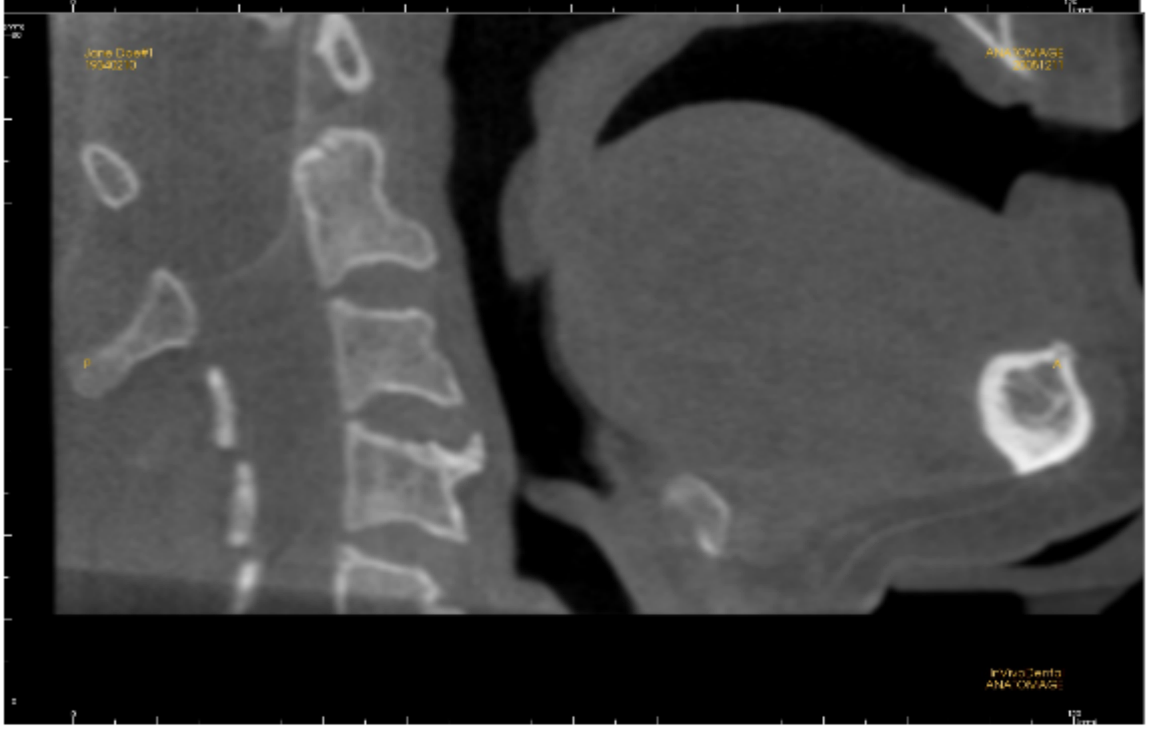
3) The feature in the center of the following image from the Jane Doe volume represents:



- normal condyle anatomy
- bifid condyle
- degenerative joint disease
- anteriorly displaced articular disc

4) What condition is illustrated in the following two images from the Jane Doe volume?





- deviated nasal septum
- fractured vertebra
- cervical spine osteoarthritis
- macroglossia

5) The structure contained within the rectangle in this Jane Doe image is most likely:

- ☐ sella turcica
- ☐ crista galli
- ☐ artifact
- ☐ head positioner

6) What are your radiographic impressions for the Jane Doe case?

7) The areas within the circles in the following John Doe image indicate the presence of:

- incisive canal cyst
- osteomyelitis
- osteoporosis
- fibrous healing defect

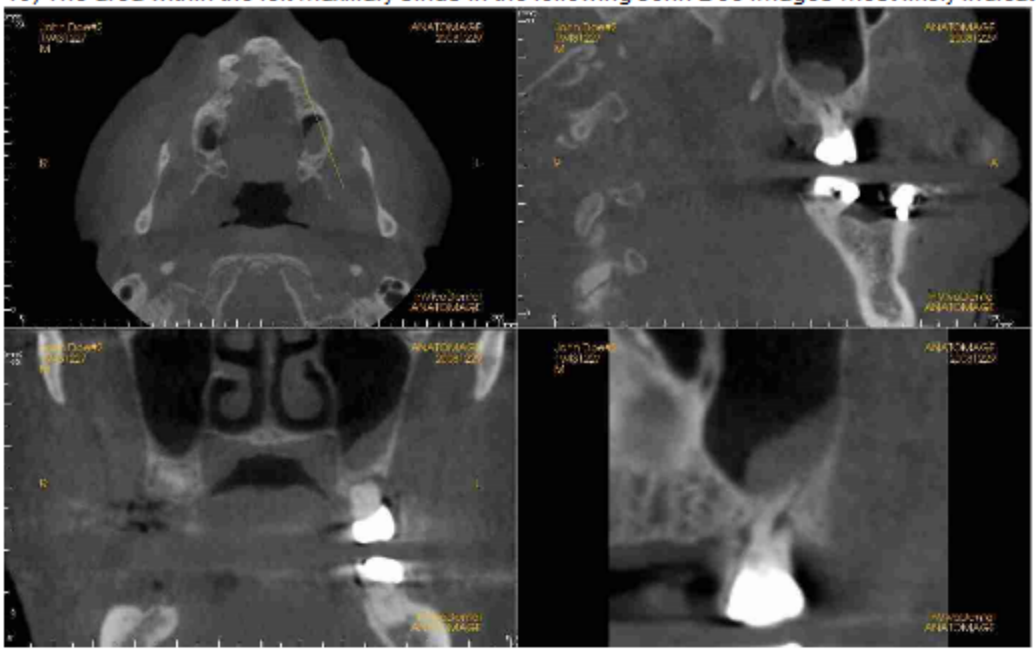
8) The areas within the circles in the following John Doe images most likely indicate:

- calcified carotid atheromas
- tonsiloliths
- styloid processes
- parotid sialoliths

9) The areas within the circles in the following John Doe images most likely indicate:

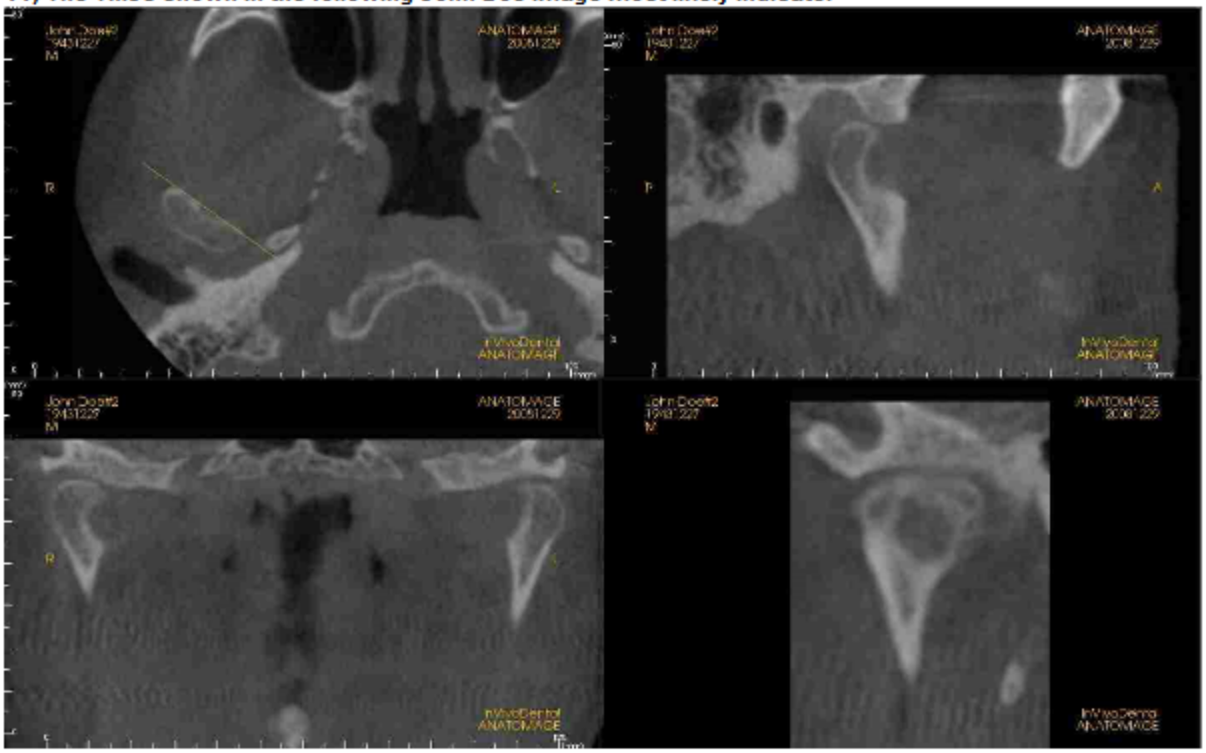
- calcified carotid atheromas
- tonsiloliths
- calcified stylohyoid ligaments
- submandibular gland sialoliths

10) The area within the left maxillary sinus in the following John Doe images most likely indicates:



- ☐ generalized sinusitis
- ☐ sinus polyp
- ☐ localized sinusitis of odontogenic origin
- ☐ mucous retention cyst

11) The TMJs shown in the following John Doe image most likely indicate:



- subchondral cyst
- osteophyte
- normal anatomy
- rheumatoid arthritis

12) What are your radiographic impressions for the John Doe case?

Thank you again for your time and commitment to the UNC Cone Beam Interpretation Study. The results of the study will be used for the improvement of educational programs in the area of cone beam CT. We appreciate your effort!!

The link to the second online survey is:
http://uncodum.qualtrics.com/SE?SID=SV_5dTvZfzXqzHq2JS&SVID=Prod

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