Published in final edited form as:

J Vet Dent. 2015 ; 32(2): 80–86.

Comparison of the Diagnostic Image Quality of the Canine Maxillary Dentoalveolar Structures Obtained by Cone Beam Computed Tomography and 64-Multidetector Row Computed Tomography

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Summary

The objective of this blinded study was to validate the use of cone beam computed tomography (CT) for imaging of the canine maxillary dentoalveolar structures by comparing its diagnostic image quality with that of 64-multidetector row CT. Sagittal slices of a tooth-bearing segment of the maxilla of a commercially purchased dog skull embedded in methyl methacrylate were obtained along a line parallel with the dental arch using a commercial histology diamond saw. The slice of tooth-bearing bone that best depicted the dentoalveolar structures was chosen and photographed. The maxilla segment was imaged with cone beam CT and 64-multidetector row CT. Four blinded evaluators compared the cone beam CT and 64-multidetector row CT images and image quality was scored as it related to the anatomy of dentoalveolar structures. Trabecular bone, enamel, dentin, pulp cavity, periodontal ligament space, and lamina dura were scored. In addition, a score depicting the evaluators' overall impression of the image was recorded. Images acquired with cone beam CT were found to be significantly superior in image quality to images acquired with 64-multidetector row CT overall, and in all scored categories. In our study setting, cone beam CT was found to be a valid and clinically superior imaging modality for the canine maxillary dentoalveolar structures when compared to 64-multidetector row CT.

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Introduction

The specialty of veterinary dentistry and oral surgery has grown tremendously in the last 20-years. As a result, the knowledge base of veterinary specialists, sophistication of diagnostic imaging modalities and treatments, and public awareness of the importance of orofacial health for their pets has expanded exponentially. Advanced treatment of dentoalveolar and maxillofacial pathology has become commonplace for dogs. Successful diagnosis and treatment of dentoalveolar and maxillofacial pathology may be enhanced by detailed, high-resolution, three-dimensional (3-D) imaging.

Traditional skull radiographs have been reported to be inferior to computed tomography (CT) for imaging advanced pathology of the maxilla, caudal mandible and temporomandibular joint.^{1,2} Computed tomography, where available, has largely replaced the use of traditional radiography for imaging these anatomical regions because of the ability to provide a three-dimensional image of the pathology.¹ Further advances have been made by the use of multidetector row CT, increasing speed of acquisition and image resolution. However, CT still provides a lower spatial resolution than radiography and, therefore, limits detailed depiction of dentoalveolar structures that are so often intimately associated with orofacial pathology.³

Cone beam CT has been shown to provide high quality image contrast and spatial resolution of dentoalveolar and maxillofacial structures, while still providing the capacity for accurate evaluation of the complex 3-D structures of the orofacial region in humans where its use in periodontics, endodontics, orthognathic surgery, oral surgery, dental implantology, and trauma management has been shown to be useful.⁴⁻⁶ Therefore, cone beam CT may prove to be the next major advancement in veterinary dentoalveolar and maxillofacial imaging. However, a standardized comparison between cone beam CT imaging and 64-multidetector row CT imaging in animals is needed.

Cone beam CT has been evaluated in dogs and cats.^{7,8} In one of these studies, panoramic, half-panoramic, and parasagittal reconstructions were created in order to evaluate image quality.⁷ The authors reported moderate image quality and concluded that cone beam CT may serve academic research better than a clinical setting. The other study utilized both cone beam CT and intraoral radiography to evaluate maxillofacial conditions in clinical patients with oral disease and found that cone beam CT provided clinically relevant information.⁸ The authors concluded that cone beam CT was “an effective auxiliary method for diagnosing most canine and feline diseases”. However, neither study utilized an image scoring system or made a direct comparison between cone beam CT and 64-multidetector row CT.

In addition, dogs have been used as a model for evaluation of the efficacy of cone beam CT at measuring 1) periapical bone loss in experimentally produced apical periodontitis,⁹⁻¹¹ 2) periapical bone repair after endodontic treatment in experimentally produced apical periodontitis,¹² and 3) peri-implant bone defect regeneration after experimentally produced bone defects and implant placement.¹³ However, none of these studies addressed the question of image quality of cone beam CT as it compares to 64-multidetector row CT.

The primary objective of the research described here was to validate the image quality of cone beam CT imaging of the canine maxillary dentoalveolar structures, when compared to 64-multidetector row CT. Our central hypothesis is that, compared to the quality of 64-multidetector row CT images, cone beam CT images are superior in their ability to accurately represent the dentoalveolar structures (alveolar trabecular bone, lamina dura, periodontal ligament space, enamel, dentin and pulp) of the dog.

Material and Methods

A segment of the right maxilla was cut including teeth between the third premolar and first molar of a commercially purchased mesaticephalic dog skull. The segment of maxilla included the hard palate ventrally and the nasal cavity and maxilla bone dorsally, and extended medially to midway between the palatal midline and the dental arch. The segment was then embedded in self-polymerizing transparent methyl methacrylate (Fig. 1). After the methyl methacrylate had polymerized, horizontal grooves measuring 2-mm deep $\times$ 2-mm wide were placed in the ventral portion of the maxilla segment using a pear-shaped, diamond bur in a high-speed dental handpiece. The grooves served as a future alignment mechanism for the maxilla segment in a vinyl polysiloxane (VPS) base. The VPS base was made such that it interdigitated with the alignment grooves that were cut in the maxilla segment upon polymerization. The maxilla segment was removed from the VPS base and cut into 2-mm thick sagittal slices in a rostral to caudal direction parallel to a plane that ran through the root canal of the mesiobuccal and distal roots of the maxillary fourth premolar tooth (108) [Fig. 2]. A total of 10 bone slices were made in this fashion from lateral to medial toward the palatal midline. Each slice was then evaluated to determine the most representative slice that included trabecular bone, lamina dura, periodontal ligament space, dentin, pulp cavity, and enamel. A photographic image of a single representative bone slice was made.

The bone slices were then placed back in sequence and secured to the VPS base. The segment was then imaged using a 64-multidetector row CT^a unit in helical mode (Table 1). The segment was aligned rostrocaudally in the Z-direction of the scanner, comparable to how a canine patient head would be positioned. The segment was then imaged as a unit in a cone beam CT^b unit with a high-resolution function (Table 1).

The 64-multidetector row CT and cone beam CT scans were reviewed by a veterinary radiologist and veterinary dentist in sagittal reformat using dedicated DICOM viewing software^c,¹⁴ at a window level of 1396 Hounsfield units (HU) and window width of 5468 HU to determine the image that best represented the anatomical structures of the dentoalveolar apparatus and best matched the dental root form of the chosen bone slice. Three prints containing the photograph of the bone slice and the corresponding cone beam CT and 64-multidetector row CT images with the same enlargement ratio were then made from a solid ink printer^d with high resolution/photo settings on photo paper using 300 DPI source images. Three different scoring experiments were set-up from the chosen images. In

^aGE Discovery CT750 HD, GE Health Care, Buckinghamshire, UK

^bSorodex Scanora 3D, Soredex, Tuusula, FI

^cOsirix Open Source Imaging Software v 4.1, www.osirix-viewer.com

^dPhaser 8560DT, Xerox Corporation, Norwalk CT, USA

experiment#1, a 13-cm display field of view (DFOV) 64-multidetector row CT image (identified only as image A to the evaluators) was compared to the cone beam CT image (identified only as image B to the evaluators) [Fig. 3]. In experiment#2, the images were switched so that image A was the cone beam CT image and image B was the 13 cm DFOV 64-multidetector row CT image (Fig. 4). In experiment #3, an 8-cm DFOV 64-multidetector row CT image (identified only as image A to the evaluators) was compared to the cone beam CT image (identified only as image B to the evaluators) [Fig. 5]. In each experiment, the evaluators were asked to compare image A to image B in respect to the ability of the image to accurately reproduce the structures observed in the photograph of the bone slice. Four investigators (1 board-certified veterinary dentist, 2 board-certified veterinary radiologists, and 1 board-certified human oral radiologist) evaluated and scored the images. The observed items that were scored included: trabecular bone, enamel, dentin, pulp cavity, periodontal ligament space, and lamina dura. The observers' impression of the overall image quality was also scored. Each experiment was performed 1-week apart and the evaluators were advised to discard results of the previous experiment so they could not be referenced when performing the next experiment. Evaluators assigned a score for each of seven observed items as follows: Score 1: Image A is greatly inferior in quality and reproducibility to image B; Score 2: Image A is slightly inferior in quality and reproducibility to image B; Score 3: Image A is equal in quality and reproducibility to image B; Score 4: Image A is slightly superior in quality and reproducibility to image B; Score 5: Image A is greatly superior in quality and reproducibility to image B.

Statistical Analysis

Repeated measures ANOVA with evaluator as a random effect was used to assess the differences in average rating between 8-cm and 13-cm DFOV 64-multidetector row CT images across the experiments. Assessing whether there was a difference in consistency of reporting between experiment #1 (13-cm DFOV CT was image A and cone beam CT was image B) and experiment #2 (cone beam CT was image A and 13-cm DFOV CT was image B) we first took the inverse responses from experiment #2 ($5 \rightarrow 1$, $4 \rightarrow 2$, etc.) and then conducted a repeated measures ANOVA. Assessing whether the cone beam CT image was preferred over either of the 64-multidetector row CT images was conducted with repeated measures ANOVAs against a null hypothesis that the average score was 3. Based on the 1 to 5 scoring system if there was no preference for cone beam CT or either of the 64-multidetector row CT images than the average score should have been 3. Therefore, if the scores were significantly different than 3 we would know that one method was preferred over the other. A two-sided significance level was set at $P < 0.05$. Lastly, inter-rater reliability was assessed with the intra-class correlation coefficient.

Results

The results of experiment #1 showed the 13-cm DFOV 64-multidetector row CT image to be significantly inferior in image quality and anatomical reproducibility compared to the cone beam CT image overall ($P < 0.001$) and in all scored categories ($P = < 0.001-0.007$) except pulp cavity ($P = 0.299$). The mean score for the 13-cm DFOV 64-multidetector row CT image was < 1.75 in all scored categories except for pulp cavity, which was 2.25 (Table 2).

The results of experiment #2 showed the cone beam CT image to be significantly superior to the 13-cm DFOV 64-multidetector row CT image overall ($P < 0.001$) and in all scored categories ($P = < 0.001-0.007$). The mean score for the cone beam CT image was > 4.25 in all scored categories (Table 3). No significant difference was seen in the consistency of the scoring between experiment 1 and 2 ($P = 0.498$). The results of experiment #3 showed the 8-cm DFOV 64-multidetector row CT image to be significantly inferior to the cone beam CT image overall ($P < 0.001$) and in all scored categories ($P = < 0.001-0.007$). The mean score for the 8-cm DFOV 64-multidetector row CT image was < 1.75 in all scored categories (Table 4). In addition, no significant difference was found in the results when comparing the 13-cm DFOV 64-multidetector row CT image with the cone beam CT image and when comparing the 8-cm DFOV 64-multidetector row CT image with the cone beam CT image ($P = 0.072$). Inter-rater reliability over all experiments was found to be high with an intra-class correlation coefficient of 0.902 (95% CI = 0.822-0.954).

Discussion

Since its introduction in the American market in 2001, cone beam CT has become an increasingly important tool for 3-D imaging in the human dental specialties.¹⁵ The popularity of cone beam CT imaging for implant planning has been driven by the ability to see the cross-sectional morphology of the jaws and the true relationship of vital anatomic structures, such as the mandibular canal and maxillary sinus, to planned implant sites. The inability to adequately assess the jaw morphology and location of vital structures with traditional two-dimensional (2-D) dental imaging, either panoramic or intraoral radiographs, led the American Academy of Oral and Maxillofacial Radiology to publish a position paper recommending the use of cone beam CT imaging for all implant assessments in all areas of the jaws.¹⁶ In the field of endodontics, cone beam CT imaging has been found to be extremely useful in the evaluation of vertical root fractures.¹⁷ With isotropic voxel sizes of 0.13-mm, cone beam CT also aids in detection of missed root canals, a common cause of failed endodontic therapy.³ Cone beam CT is also used for the assessment of internal and external root resorption.¹⁸ Oral surgeons are increasingly using cone beam CT imaging for evaluation of third molar tooth impactions and major pathology.⁵ The ability to accurately assess the extent and proximity of lesions to vital anatomy makes this a useful diagnostic and pre-surgical planning tool.⁵ In addition, cone beam CT is used in orthodontics in a variety of ways, including craniofacial morphometric analysis, evaluation of cleft palates, and orthognathic surgical planning.^{19,20}

Similar to a multidetector row CT unit, a cone beam CT unit consists of an x-ray source, image detector, computer, and an image display. However, instead of a collimated fan beam as used in CT units, cone beam geometry is used in these units. Also, different than the detectors aligned in rows used in CT units, flat panels or image intensifiers are used in cone beam CT technology. In cone beam CT, the x-ray source and the image detector rotate synchronously around the patient's head acquiring images through 360°. Reported scan time ranges between 5 and 40-seconds depending on the unit, the size of the field of view, and the resolution required.²¹ Scan time does not equal exposure time as the beam is usually pulsed. Similar to conventional CT, the acquired raw data undergoes a reconstruction process that

allows the volume to be viewed by specialized software on the monitor in multiple panes or 3-D reconstructions.

To our knowledge, this is the first published study that utilized a blinded, standardized scoring system to compare the image quality of a list of anatomical structures between the cone beam CT and the multidetector row CT image in a tooth-bearing segment of the skull of a dog. Sagittal images were utilized in order to allow for a direct comparison with a representative tooth-bearing bone slice. Our results showed that cone beam CT images are significantly superior in quality to multidetector row CT images overall and for all scored anatomical structures. Further studies to evaluate the quality of cone beam CT compared to dental radiography or multi detector row CT in clinical patients are desirable, but with the high quality images achieved in this study a good translation into clinical practice is anticipated as seen in human dentistry.

The methodology utilized was a modified version of methods described previously in which a slice of tooth-bearing bone was used as the standard by which the cone beam CT and multidetector row CT images were evaluated.²² The image quality of cone beam CT was found to be significantly superior to the image quality of multidetector row CT overall and in all 7 scored categories. We evaluated what affect the multidetector row CT DFOV would have on the image quality and found no significant difference. In addition, we found that the image quality of cone beam CT was found to be significantly superior to both the 8-cm DFOV and 13-cm DFOV multidetector row CT images. All imaging systems have an inherent imaging resolution limit. In CT units, this is determined by the focal spot and detector dimensions, acquisition mode, as well as the applied spatial reconstruction parameters.^{3,23} In a CT scanner, the X-ray tube and opposing detectors rotate around the patient and generate a circularly overlapping set of projections of attenuation data. The number of pixels of the generated image is defined by the used matrix size. The display field of view (DFOV) is the area within 1 slice from which an image with a given matrix size is generated. The larger the selected DFOV, the larger is the size of each pixel and the lower the spatial resolution of the image. Because of geometric factors (X-ray focal spot and detector size), there is a lower limit at which decreasing the DFOV does not further increase spatial resolution. In most CT units, decreasing the DFOV to less than 10 to 15-cm does not further increase image resolution.²³ Therefore, it correlates with our findings that there was no significant difference between the 8 and 13-cm DFOV images.

Proprietary spatial reconstruction algorithms are applied to the raw data acquired in CT to reconstruct the images optimally for viewing of the tissue of interest, such as bone versus soft tissues. A bone plus algorithm (high spatial frequency algorithm with additional edge enhancement filter) was applied to the multidetector row CT scans in our study as the evaluation was focused on bony structures. These algorithms vary between vendors and no conclusion can be drawn from our study regarding how a multidetector row CT unit from a different vendor would have compared to the cone beam CT examination. In addition, further advancements are being developed to improve spatial resolution in multidetector row CT using specific high or ultra-high resolution techniques, which may be available on different units or software packets.²⁴

In order to limit bias, we used 4 evaluators to score image quality. Two evaluators were board-certified veterinary radiologists with significant CT experience. One evaluator was a board-certified human oral radiologist with significant experience evaluating both multidetector row CT and cone beam CT images. The fourth evaluator was a board-certified veterinary dentist with experience evaluating CT and intraoral radiographic images of the maxillofacial region. It is important to note that, in an attempt to remove measurement bias, the evaluators were blinded to the source of the image and experiments were separated by a prolonged time interval. We found the consistency of the scores across evaluators within each scored category to be very high based on the intra-class correlation coefficient of 0.902. This is supportive of our findings of superiority of the cone beam CT images compared to the multidetector row CT images. Although the scoring system was based on a semi-subjective assessment of image quality, the high intra-class coefficient lends objectivity to the scoring system utilized. In experiment #1, evaluator A provided a score of 4 to the pulp cavity category, where all other evaluators gave a score of 1 or 2. In experiment #2, where the images from experiment 1 were simply reversed, evaluator A again gave a score of 4 (consistent with other evaluators). Had evaluator A been consistent between experiment 1 and 2, a score of 2 should have been given in experiment #1. We consider evaluator A's score for pulp cavity in experiment #1 to be an outlier. Although we did not remove the score from the statistical analysis, had evaluator A given a score of 2 for pulp cavity in experiment #1, the P value for the pulp cavity category would have been 0.007 instead of 0.299. A larger population of evaluators may have minimized the effect of this particular score on the statistical significance.

Although conventional CT systems are largely available in most veterinary teaching hospitals and many private multi-specialty practices, the private veterinary dentist may find the associated monetary and technical requirements of a CT system to be prohibitive. Human dentists and oral surgeons in private practice have similarly experienced this challenge. Considering the ease of use, high image quality, and efficiency of cone beam CT, one may posit that cone beam CT is superior to intraoral radiography and multidetector row CT within that setting. Typical cone beam CT systems do not have special electrical requirements (they can be powered by a typical 110 V or 220 V electrical receptacle) and have an initial investment significantly lower than a traditional CT system, making cone beam CT a widely utilized technology in humans. The manufacturers of cone beam CT systems have found a niche within the field of human dentistry and its many specialties. A similar niche may be present within the community of veterinary dentistry and oral surgery.

Cone beam CT may prove to be the next major advancement in veterinary dentoalveolar and maxillofacial imaging because of its ability to provide 3-D imaging at a lower cost than multidetector row CT and at a lower radiation risk, similar to intraoral radiography. Additionally, we have now established the superiority of cone beam CT imaging over 64-multidetector row CT imaging in the evaluation of the canine maxillary dentoalveolar structures as described in this study. Future efforts may include a standardized comparison between cone beam CT and multidetector row CT in other maxillofacial regions and comparison between cone beam CT and intraoral radiography.

Acknowledgments

The authors would like to thank Ms. Vicki Kalscheur, HT (ASCP), MLT of the University of Wisconsin School of Veterinary Medicine Comparative Orthopedics Research Laboratory for her invaluable technical assistance with preparation of the maxilla sample. In addition, the authors would like to thank Mr. Doug Woods and Mr. Jim Libenstein of Soredex for the generous donation of their time and technical assistance during the cone beam CT scanning phase of this project as well as Alice Minx of the Wisconsin Institute for Medical Research for assistance in acquiring the multidetector row CT exams. Lastly, Dr. Dale Bjorling is to be thanked for his thoughtful review of the study design. This study was supported by University of Wisconsin School of Veterinary Medicine Companion Animal Grant and, in part, by the University of Wisconsin Institute for Clinical and Translational Research (UW ICTR), funded through an NIH Clinical and Translational Science Award (CTSA), grant number 1 UL1 TR000427, NCATS.

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Figure 1. Photographs of the maxillary segment utilized in this study containing the third premolar (arrow) through the first molar (arrowhead) teeth before (A) and after (B) embedding in methyl methacrylate.

Figure 2. Photographs of the maxillary segment-containing block of methyl methacrylate depicting the orientation grooves (A) and the vinyl polysiloxane base (B) used to stabilize and orient the block after it was sliced into 2-mm thick sections using a water-cooled, diamond blade saw (C).

Figure 3. Photographs of the original block specimen from experiment # 1 with the 13-cm DFOV multidetector row CT (A) and cone beam CT (B) images.

Figure 4. Photographs of the original block specimen from experiment # 2 with the cone beam CT (A) and 13-cm DFOV multidetector row CT (B) images.

Figure 5. Photographs of the original block specimen from experiment # 3 with the 8-cm DFOV multidetector row CT (A) and cone beam CT (B) images.

Table 1

Exposure settings for cone beam CT and multidetector row CT utilized in the study.

Cone Beam CT	
Tube Voltage	90 kVp
Tube Current	13 mAs
Exposure Time	4.5 s
Voxel Size (Resolution)	0.13 mm ³
Field of View	6 cm
Multidetector Row CT	
Tube Voltage	120 kVp
Tube Current	163 mAs
Tube Rotation Time	0.5 s
Scan Mode	Helical
Pitch	0.31
Slice Thickness and Reconstruction Interval	0.625 mm
Display Field of View	13 cm [*] , 8.9 cm [†]
Number of Detector Rows Utilized	64
Spatial Reconstruction Filter	High frequency (proprietary name: bone plus with medium filter)

* = Experiments # 1 & 2;

† = Experiment # 3

Table 2

Experiment #1: comparison of the 13-cm DFOV multidetector row CT image^{*} with the cone beam CT image[†].

Observation Item	Evaluator					Mean	SD	95% CI	P value
	A	B	C	D	D				
Trabecular bone	2	2	1	2	2	1.75	0.50	1.06 – 2.44	0.007
Enamel	1	1	2	2	2	1.50	0.58	0.70 – 2.30	0.007
Dentin	2	2	1	2	2	1.75	0.50	1.06 – 2.44	0.007
Pulp Cavity	4	1	2	2	2	2.25	1.26	0.50 – 4.00	0.299
Periodontal Ligament Space	1	1	1	1	1	1.00	0.00	1.00 – 1.00	< 0.001
Lamina Dura	1	1	1	2	2	1.25	0.50	0.56 – 1.94	0.002
Overall Impression	1	1	1	2	2	1.25	0.50	0.56 – 1.94	0.002

^{*} = Figure 1, Image A;

[†] = Figure 1, Image B

Table 3

Experiment #2: comparison of the cone beam CT image^{*} with the 13-cm DFOV multidetector row CT image[†].

Observation Item	Evaluator					Mean	SD	95% CI	P value
	A	B	C	D	D				
Trabecular bone	5	5	5	4	4	4.75	0.50	4.06 – 5.44	0.002
Enamel	4	5	4	4	4	4.25	0.50	3.56 – 4.94	0.007
Dentin	4	4	5	4	4	4.25	0.50	3.56 – 4.94	0.007
Pulp Cavity	4	4	4	5	5	4.25	0.50	3.56 – 4.94	0.007
Periodontal Ligament Space	5	5	5	5	5	5.00	0.00	5.00 – 5.00	<0.001
Lamina Dura	4	5	5	5	5	4.75	0.50	4.06 – 5.44	0.002
Overall Impression	4	5	5	5	5	4.75	0.50	4.06 – 5.44	0.002

^{*} = Figure 2, Image A;

[†] = Figure 2, Image B

Table 4

Experiment #3: comparison of the 8-cm DFOV multidetector row CT image* with the cone beam CT image†.

Observation Item	Evaluator				Mean	SD	95% CI	P value
	A	B	C	D				
Trabecular bone	2	2	1	1	1.50	0.58	0.70 – 2.30	0.007
Enamel	1	1	2	1	1.25	0.50	0.56 – 1.94	0.002
Dentin	2	2	2	1	1.75	0.50	1.06 – 2.44	0.007
Pulp Cavity	1	1	2	1	1.25	0.50	0.56 – 1.94	0.002
Periodontal Ligament Space	1	1	1	1	1.00	0.00	1.00 – 1.00	< 0.001
Lamina Dura	1	1	1	1	1.00	0.00	1.00 – 1.00	< 0.001
Overall Impression	1	1	1	1	1.00	0.00	1.00 – 1.00	< 0.001

* = Figure 3, Image A;

† = Figure 3, Image B