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Dimensions of First Molar Radicular Bone Near the Maxillary Sinus in the Human. A Comparison of Cone Beam Computed Tomography Analysis and Gross Anatomical Dissection.

by

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THESIS

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I am fortunate to have found dentistry as the professional endeavor of my lifetime.

Dimensions of First Molar Radicular Bone Near the Maxillary Sinus in the Human. A Comparison of Cone Beam Computed Tomography Analysis and Gross Anatomical Dissection.

Robert B. Howe, DDS

Abstract

Concepts of how the maxillary dentition relate to the maxillary sinuses has evolved from dissection studies on cadavers to comparing images taken with high-resolution digital radiography and three-dimensional reconstructions. This study dissected the human maxilla and sinus to provide linear measures with physical calipers as a standard to which radiographic images from cone beam computed tomography (CBCT) were compared. The Hitachi CB MercuRay CBCT system was used to scan 37 cadaveric maxillae, and the images were reconstructed using CBworks 1.0. The detailed dissections of 69 first molars provided data to determine the relationships of molar roots to the sinus and oral cortical plates, and to serve as a basis for future studies in human subjects to determine the projected development of the maxillary sinus with age. Comparison of the measures from the radiographic rendered images to the physical measures by Bland-Altman analysis indicated that CBCT data was in sufficient agreement for clinical relevancy while offering the advantage of being non-invasive. The data showed there was a high agreement in the measures between the two methods.

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Dimensions of First Molar Radicular Bone Near the Maxillary Sinus in the Human. A Comparison of Cone Beam Computed Tomography Analysis and Gross Anatomical Dissection.

Introduction

The sinus of the maxilla had been described as "mysterious" by anatomists, dentists, and proponents of focal infection in the early twentieth century.[1-3] Anatomical interest dominated the early decades and waned by mid-century. In the second half of the 20th century, sinus studies focused more on the effects of sinusitis and its inflammatory or microbiologic etiology.[4-12] Toward the end of the last century, tomography and endoscopy were introduced as diagnostic advances that extended therapeutic modalities and renewed anatomical interest in the maxillary sinus. More dental surgical procedures have been performed near the maxillary sinus due to advances in implant dentistry, bone grafting sinus lifts, and endodontic surgeries. Dentistry has expanded its interest into this region, which has lacked complete understanding for many decades. This study compared images obtained with cone beam computed tomography (CBCT) to the gold standard of gross dissection and physical caliper measurement for a study of the maxillary sinus.

The maxillary bone, that delineates the sinus, contains the tooth roots, and defines the field in which radicular surgeries take place, is variable and difficult to describe. Yet, investigators who have dissected maxillae would be delighted by the descriptive accounts in the literature prior to the 20th century. Tendencies and variations can be recognized in anatomical relationships, and it is important to understand the anatomical relationship of teeth and alveolus to the maxilla and sinus. Surgical procedures are complicated by sinus membranes that can be torn, or by debris pushed into the sinus and difficult to retrieve. This study evaluated the ability of CBCT to adequately describe an individual surgical site with minimal bony dimensions.

The maxillary sinus was known to grow in the child, and it was claimed to be stable in the young adult.[1,13] Longitudinal studies of potential sinus development in the adult years are lacking and desirable. The bony sinus above the posterior teeth and below the orbit has not been readily accessible for study *in vivo*. If the new CBCT technology is comparable to anatomic dissection,[14] then anatomic study of the sinus will no longer be limited to older populations of medical cadavers.

Literature Review

Garretson noted in 1873 that accounts of disease in the Antrum of Highmore were often "as anomalous in principle as they are in description" and concluded, that if taken as accurate, "that the antrum has some of the strangest anomalies."[3] John Marshall M.D. mentioned Garretson's bias, and devoted four chapters to diseases of the maxillary sinus in his text on oral pathology in 1909.[15] He maintained that many diseases afflicted the sinus such as syphilis, cysts and tumors, that massive drainage from other sites often collected in the sinus, and that necrotic sinus walls were not uncommon. Few journal titles conveyed the mystique of the maxillary sinus as well as "Eighteen Hundred Years of Controversy: The Paranasal Sinuses." Anatomists Blanton and Biggs in 1969 described unresolved controversy over fundamental function and developmental significance of these cranial structures.[2] They wrote: "The mystery of the significance of the paranasal sinuses of man is time-honored." Referring to this in 1980, Branislav Vedić wrote in the maxillary sinus chapter of Orban's Oral Histology and Embryology[1]: "The maxillary sinus, more than any other of these cavities, has been subjected to peculiar interpretations throughout history."

Focal infection proponents had significantly lost credibility by 1940, but influenced suspicion about endodontics and the maxillary sinus for many succeeding years. William Bauer published a detailed histological study on the effects of dental pathology upon the bone and mucosa of the maxillary sinus.[16] Like many authors, he attempted to weigh his findings against the wide spectrum of contrary opinions about the maxillary sinus. However, in the tone of his conclusion in 1943, he sided with proponents of focal infection, and recommended extraction for teeth near the sinus with advanced or questionable pathology. As late as 1971, Waite wrote: "It appears quite obvious that the paranasal sinuses, and particularly the maxillary sinus, are important focal points for the harboring and spreading of infection." [17]

The anatomical studies of the early twentieth century often presented contrary statements about features of the maxillary sinus. For example, the basic shape was described as a three-sided pyramid,[13,18] or a four-sided pyramid,[1,19] with the base of the pyramid against the medial wall of the nasal cavity. Sinus morphology was noted as variable, leading to completely opposite theories for the development of identifiable trends and features. There were contrary opinions about the effects of chronic infection or premature loss of teeth upon sinus expansion. Accounts varied that these basic events generally caused osteogenic or osteolytic effects on the bone around the antrum. The maxillary sinus was described as presenting anatomic complexities defying treatment, next to a paper stating that the subject of antral treatment had been exhausted.[20]

Mr. Underwood was Professor of Dental Surgery at King's College, London, and his preliminary findings presented in 1908 preceded publication of his full study in 1910, often cited in maxillary sinus literature.[20,21] His full study was narrative in nature and provided no systematically collected data. A bony septum of the maxillary sinus is infrequently called Underwood's septa.[19] Further, in the interest of correct use of historical terms, C.V. Schneider (1614-1680), a German anatomist, was given credit as a leading proponent that the sinus was normally filled only with air, and not mucous humor associated with animal spirits.[2] The term "schneiderian membrane" is usually not capitalized in the literature and refers to all nasal mucosa. The term does not pertain exclusively to the Antrum of Highmore.

Another paper in 1910 presented significant amounts of data pertinent to the development of the maxillary sinus. J. P. Schaeffer interpreted Highmore (1651) in Latin as well as extensive research published in German with regard to sinus growth in childhood.[13] The data largely measured sinus growth with age with three linear vectors, and provided data on sinus volume as measured by liquids. However, the usefulness of the data was limited without other skeletal parameters given the highly variable morphology of the sinus in skeletons of different size. Schaeffer reported: "The sinus reaches its full size between the fourteenth and eighteenth year." No data was presented on the subject of posterior teeth relative to the sinus floor.

Mustian wrote in 1933 that for the purpose of his research, 4,000 observations were made on 100 human maxillary sinuses. His specimens were past middle age and obtained at the Northwestern University Dental School. His observations were generally sorted into nominal categories represented by percentages.[22]

Mårtensson wrote about dental injuries following radical surgery of the maxillary sinus.[23] In his introduction, he provided rare data relative to this present study. He cited the distance of first molar apices to the maxillary sinus in non-English journals with studies on Finnish skulls by Von Bonsdorff (84 skulls; 1924), and Paatero (11 skulls; 1939).[24,25] Results from these two studies were presented as 2.6 mm, and 2.0 mm (± 0.89), respectively, with no description of how these measurements were made. Von Bonsdorff was also cited as reporting that facial walls of the sinus were 0.5-1.5 mm thick, which was consistent with the general observations of this study.

Eberhardt published "A Computed Tomographic Study of the Distances Between the Maxillary Sinus Floor and the Apices of the Maxillary Posterior Teeth" in 1992.[26] This paper purported to be the first of its kind to utilize tomography as a research tool for studying the apices of the teeth in relation to their surrounding structures. "The objectives of this study were to determine the distances between the apices of the maxillary posterior teeth and the floor of the maxillary sinuses, and the thickness of the lateral bone covering these apices." Tomographic data from 38 human subjects and 12 autopsy specimens were analyzed. Details about methodology were minimal and confusing. "Measurements were made by depositing one reference cursor at the root apex and another at the floor of the sinus. Values were displayed to the nearest 0.1 mm. For purposes of data analysis, apices extending above the floor of the sinus were assigned negative values whereas those below the sinus floor were assigned positive values." Measurements for posterior teeth were averaged between right and left maxillary arches. The tomographic scans were "high resolution thin sections" of 1.5 mm thickness using a General Electric 9800 CT/T Quick CT scanner and software (New Berlin, Wisconsin).

A study in 2006 by Velloso inadvertently demonstrated the limited usefulness of the term "sinus floor" in examination of preoperative computerized tomographies of 15 patients selected for sinus lift procedures in Brazil.[27] The purpose of the study was to evaluate the angulations of the maxillary sinus walls at the radicular periapical sinus region. The study demonstrated that the "sinus floor" could be thought of as an angle between medial and lateral walls which demonstrated greater characteristics of a plane. Smaller angulations of these walls were purported to cause more difficulty in dissection of the antral mucosa, leading to tears and perforations causing sinus lift complications. The tomographic slices in this study were 1 mm thick.

Moore studied the reliability of endoscopy to identify anatomical landmarks in the maxillary sinus roof (i.e., orbital floor) in six fresh cadavers via a Caldwell-Luc approach.[28] The purpose of the study was to define consistent landmarks and establish endoscopic repair of orbital blow-out fractures as a predictable and reliable treatment alternative to open surgical technique. He noted that maxillary sinus endoscopy provides a complex and disorienting view of the anatomy as "there is significant pleomorphism within cranio-facial air spaces." Anatomic averages measured with endoscopic examination were compared to plastic molds, computed tomography, and digital images. The tomographic data for this study in 2008 was obtained from 1.2 mm axial slices.

Selcuk published a study in 2008 from Turkey of 330 consecutive tomography scans of the paranasal sinuses.[29] His data quantified variations of maxillary sinus anatomy "which may sometimes cause symptoms that may lead patients to present to various departments like ophthalmology or dentistry, rather than the ENT department." Among the variations identified were location, position and number of septa, hypoplasia, overpneumatization, ethmoidal cell anomalies, and extension of the maxillary sinus through the frontal recess. His study was relevant to characterizations in older anatomical research but not to the present study. This study utilized tomography scans obtained in 3 mm section thickness and interval.

Hypothesis

This study compares identical data sets of linear measurements taken from bone around maxillary first molar roots. The data sets test the ability of CBCT to obtain measurements that are as valid as those generated by gross anatomical dissection and physical caliper measurement. The implicit null hypothesis is that no significant relationship of the data sets can be demonstrated. In evaluating whether two measurement approaches are equivalent, a high correlation between the methods is a minimal requirement. For these purposes, a Pearson correlation coefficient of linear regression (*r*) above 0.8 value is desirable. Additionally, the agreement and variability of these measurement techniques are analyzed utilizing Bland-Altman statistics.[30,31] These results are compared to an operational definition of reasonable clinical accuracy for acceptance or rejection of the validity test between the two measurement systems.

Specific Aims

This study aimed to compare extensive data sets obtained by two different methods. Data was collected for maxillary first molar teeth which were three rooted. For each root, the smallest distance from the root apex to the maxillary sinus was measured, and the minimum thickness of bone to the nearest cortical plate was measured. For buccal roots, the distance to the facial cortical plate was measured, and for palatal roots, the distance to the palatal cortical plate was measured. Six data points were collected for each molar tooth. Thirty-seven maxillae pairs with 69 first molars yielded a data set of 414 data points. Two equivalent data sets were obtained by gross physical dissection and by CBCT radiographic scan, and compared.

A surgeon would hope to work in a surgical field where all aspects of the site had been physically measured. A radiologist would believe this is possible non-invasively. This study tested the reliability of CBCT to obtain measurements that physical dissection would yield of bony dimensions around maxillary first molar tooth roots relative to the maxillary sinus and the nearest oral cortical plate. If CBCT were validated to obtain these physical measurements, then CBCT would be demonstrated to be a valid tool to study the dynamic pneumatization of the maxillary sinus over life spans in living human subjects.

The projected course of human maxillary sinus development could also be examined three-dimensionally and volumetrically utilizing digital reconstruction software.

Materials and Methods

Thirty-seven human maxillae were obtained after dissection by medical and dental students in separate gross anatomy courses, while all specimens originated from the UCSF Willed Body Program. Specimens were selected if they possessed largely intact posterior tooth rows with the presence of first molar teeth. Mean age at time of death was 76 years (± 15.6 SD). Research on cadaveric remains is not subject to human subjects' regulations as confirmed by the UCSF Committee for Human Research. A formal arrangement for disposal of remains was made with Touro University College of Osteopathic Medicine (TUCOM) where specimens were dissected for the study. The Institutional Review Board (IRB) at TUCOM approved the study.

The specimens had all been sectioned in half, at the midline of the sagittal plane, which is a common practice in gross anatomy courses. The resulting dental quadrants were stripped of soft tissue, and individually mounted in rectangular plastic boxes. The pre-existing sagittal dissection plane and walls of the specimen boxes allowed the mounting of specimens, two pairs at a time, in orthogonal orientation for tomography scanning. Four boxes housing two maxillae were taped together and wrapped in clean plastic film as a barrier method to meet infection control standards of the UCSF School of Dentistry where CBCT scans were obtained.

The CBCT scans were taken with a CB MercuRay™ (Hitachi Medico Technology, Tokyo, Japan). A 10-second scan acquires 512 images in a 12" diameter spherical volume with 0.2-0.376 mm^3 voxels in high-resolution mode and 12 bits/voxel ($2^{12} = 4096$ shades of gray). The version of the system used in this study has a scalable 12" CCD detector that can be set in several fields of view (FOV) modes. The implant (I) mode for detailed imaging has a 10-cm FOV at a resolution of 0.2 mm^3. The data in DICOM format was viewed and manipulated by CBworks™ software (CBworks 1.0, CyberMed Inc., Seoul, Korea).

After tomography scanning, the specimens were dissected manually to obtain the first data set. Dissection proceeded with a dental lathe, and with attachments as used in denture fabrication and finishing. An Iwanson Crown & Bridge gauge (Miltex, York, PA) was used with the aid of basic dental loupes to obtain measurements to a precision of 0.1 mm. The specimens were serially destroyed by sectioning and extracting one molar root at a time, similar to techniques used in oral surgery, as data was collected. Unlike work on living patients, the resulting cadaveric sockets could be physically measured for the bony dimensions of the data set.

After the isolation of an individual molar root socket, the minimum distance to the maxillary sinus and appropriate cortical plate was measured (Figure 1). The minimum distance to the sinus was taken from the apex of the socket, while measurements to the nearest cortical plate were obtained from a point 3 mm coronally to the socket apex. This practical method obtained a minimal measurement as dictated by typical apical root geometry, and coincided with endodontic surgical technique in which the apical 3 mm of a root is resected. All dissections and physical caliper measurements were completed by the author.

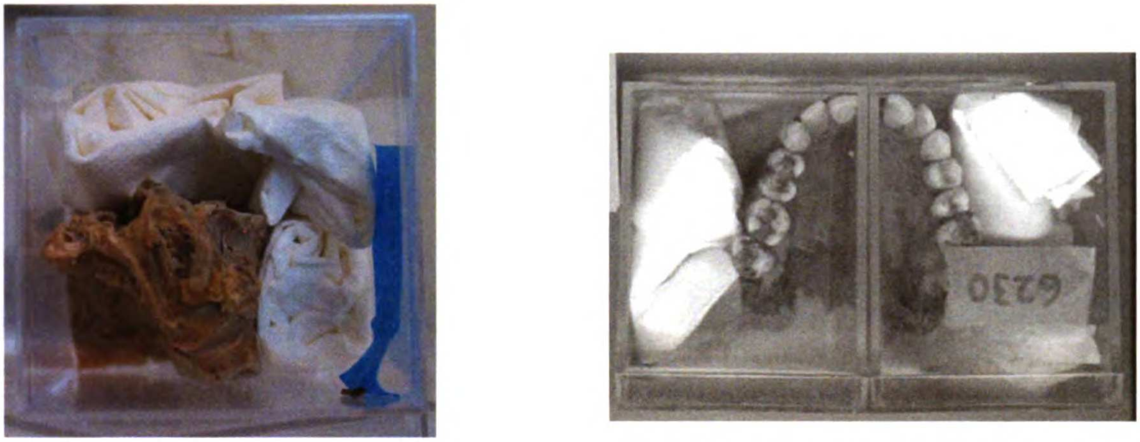
Tomographic analysis was completed after the manual dissection of specimens. The tomography scans in DICOM format were viewed utilizing CBWorks software. The software program allowed visualization and selection of the coronal plane that best divided each root apex in half, mesially and distally (Figure 2).

Measurement tools in the software provided linear data by manipulation of cursors to an accuracy of 0.1 mm. As in the procedure for manual dissection, the distance from the apex of the root socket to the maxillary sinus was obtained. For measurements to the nearest cortical plate, the apical 3 mm of the root was measured and marked, then the data point was measured at that transverse plane of the tooth root. The computer images of these coronal planes and measurements were recorded, and the data was transferred to paper data records identical to those of manual dissections. The tomographic analysis was divided in half between the author and a faculty member in gross anatomy familiar with the project.

The tomographic data was collected in coronal planes that were more strictly defined than the manual dissections. However, it was evident that placement of the measurement cursors sometimes obscured the scale of the image being measured, and the computer would not always allow manipulations of the cursors on the order of 0.1 mm as implied in the data. A practical solution to this problem was to take two measurements from an arbitrary third point on the screen, and the difference between these larger measurements was then equal to the data point. The other problem encountered was that some scans exhibited more scatter interference than others making it difficult to read obscured images. This problem seemed to correlate more to the scanning date than to the amount of metal in the specimen, which is the accepted cause of scatter interference. The initial group of scans presented the greatest image distortion due to scatter interference.

Statistical Analysis

Data were compared between the two methods with the caliper measures from the physical anatomical dissections serving as the standard, to which measures from the radiographic rendered images were compared using the Pearson product-moment correlation coefficient and a Bland-Altman analysis.[30,31] The statistical program used in the study was Excel 2003 (Microsoft, Redmond, WA).



A. Single boxed specimen, posterior view.

B. A specimen pair showing full arch.

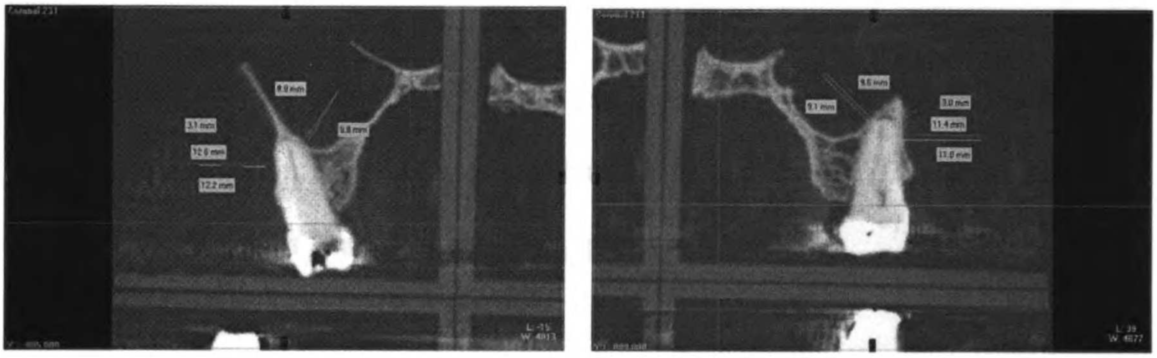
C. Boxed specimens ready for scanning.

D. Manual dissection with a dental lathe.

E. Caliper measurement of specimen.

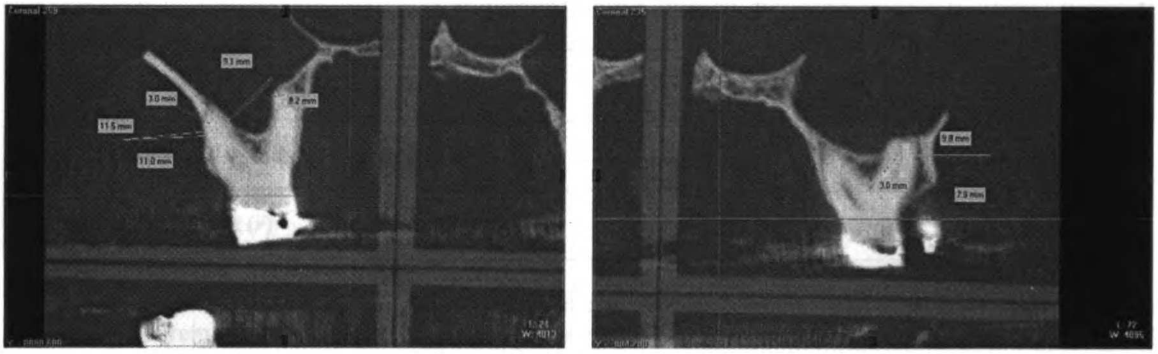
F. Interradicular fossa of a first molar.

Figure 1. Specimen boxing and manual gross dissection.



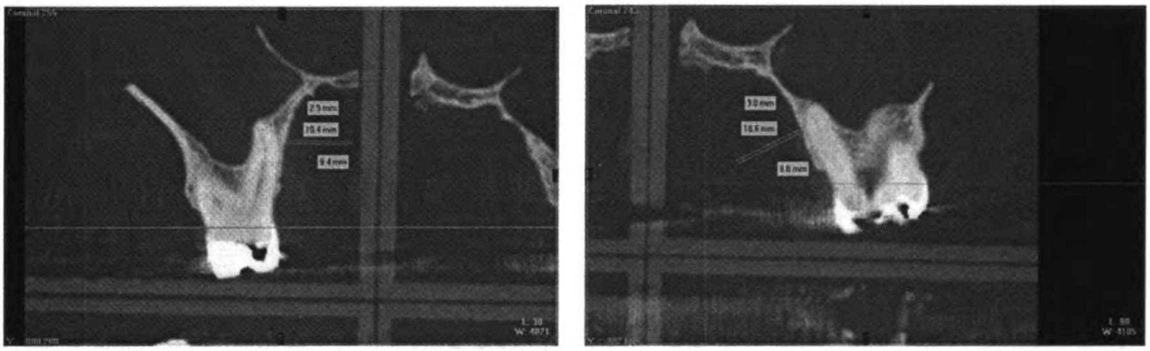
Tooth #3 MB (mesiobuccal) root

Tooth #14 MB (mesiobuccal) root



Tooth #3 DB (distobuccal) root

Tooth #14 DB (distobuccal) root



Tooth #3 PAL (palatal) root

Tooth #14 PAL (palatal) root

Figure 2. CBCT digital radiographic images (specimen #22).

Results

Table 1 below provides mean data values, classified by root type, for upper first molars, and Pearson correlation coefficients for each root type in the study. The entire study data are presented in Tables 2 and 3 on following pages.

Measurements (mm) ± (standard deviation)		Mesio-Buccal Root	Disto-Buccal Root	Palatal Root
Mean Caliper Distance:	to Maxillary Sinus	1.3 ±(2.5)	1.2 ±(1.6)	0.9 ±(2.0)
Mean Cone Beam Distance:	to Maxillary Sinus	2.5 ±(3.4)	1.8 ±(2.2)	1.2 ±(2.2)
Mean Caliper Distance:	to Cortical Plate	0.6 ±(0.6)	1.0 ±(1.0)	1.4 ±(1.0)
Mean Cone Beam Distance:	to Cortical Plate	0.7 ±(0.7)	1.1 ±(1.0)	1.4 ±(1.1)
Correlation Coefficient (*r*):	Caliper vs. CBCT	*r* = 0.85	*r* = 0.90	*r* = 0.88

Table 1. Caliper measurements, cone beam measurements, and correlation coefficients by root type. Measurements in millimeters ± (standard deviation).

Figure 3 presents the regression line and correlation coefficient for all the data in the study. Overall, the Pearson correlation coefficient of caliper measurements versus CBCT measurements was $r = 0.85$ for all of the 414 data points in each data set.

Figure 4 presents the Brand-Altman curve for all study data. The curve shows a positive bias for CBCT measurements of 0.4 mm. The standard deviation for differences of CBCT measurements minus caliper measurements over the 414 data points in each data set was 1.1 mm.

Maxillary Sinus Data **Page 1 of 2**

Specimen	Tooth	Caliper measurement						Cone beam measurement					
		Mesial buccal		Distal buccal		Palatal		Mesial buccal		Distal buccal		Palatal	
		Facial	Sinus	Facial	Sinus	Lingual	Sinus	Facial	Sinus	Facial	Sinus	Lingual	Sinus
# 01	3	0.2	8.2	0.3	7.7	4.1	2.2	1.2	15.5	1.1	12.5	2.0	5.4
	14	0.2	5.2	0.9	5.3	1.7	3.8	1.4	10.4	1.8	5.6	1.0	6.3
# 02	3	0.1	0.9	0.1	2.2	0.3	1.5	0.0	3.3	0.0	1.7	0.4	2.2
	14	0.3	2.2	0.1	1.9	0.8	1.1	0.0	4.8	0.0	3.3	0.6	1.3
# 03	3	1.4	0.0	2.7	0.0	3.4	0.0	1.0	0.0	2.6	0.0	2.8	0.0
	14	0.9	0.6	2.8	0.5	2.0	0.2	1.2	1.0	2.4	0.8	2.0	0.8
# 04	3	0.6	0.1	0.4	0.8	2.9	0.1	0.2	0.9	0.4	0.7	2.7	0.0
	14	1.0	0.1	1.7	0.1	1.2	0.4	0.9	0.1	2.2	0.0	0.8	0.8
# 05	3	1.3	0.2	0.3	0.7	0.4	0.7	1.0	0.7	0.6	1.8	0.8	0.7
	14	0.7	0.4	0.2	0.2	0.3	2.6	1.0	0.8	0.0	0.6	0.3	2.7
# 06	3	0.7	0.4	0.7	0.7	0.3	0.3	1.2	1.1	0.0	1.9	0.0	1.0
	14	1.6	0.4	0.9	1.4	0.8	0.6	1.3	3.0	0.8	1.8	0.1	0.8
# 07	3	0.9	0.8	1.7	1.0	2.9	0.9	0.8	1.6	2.2	1.2	1.9	1.4
	14	0.6	0.8	1.8	0.2	3.4	0.2	0.0	2.1	1.8	0.7	3.4	0.0
# 08	3	0.3	0.1	0.7	0.2	0.7	0.1	0.8	8.4	0.4	1.5	4.4	1.7
	14	0.6	0.4	1.3	0.2	0.5	0.2	1.0	0.8	2.0	0.3	3.1	1.2
# 09	3	0.2	0.3	2.4	0.3	3.1	0.3	0.8	0.7	3.0	0.8	3.2	0.6
	14	*	*	*	*	*	*	*	*	*	*	*	*
#10	3	0.0	0.7	0.0	0.2	0.2	0.2	0.0	1.5	0.0	0.8	3.8	0.4
	14	0.2	0.7	0.1	1.7	0.1	0.1	0.0	1.0	0.0	1.6	3.1	0.4
# 11	3	0.9	0.2	1.3	0.3	1.0	0.1	0.4	0.4	2.0	0.8	0.6	0.0
	14	0.6	0.2	0.4	0.2	1.1	0.1	0.0	1.6	1.2	1.1	0.6	0.0
#12	3	0.1	1.0	0.2	0.8	0.7	0.1	0.4	2.6	0.2	1.0	0.6	0.4
	14	0.2	0.4	0.2	0.3	0.7	0.1	0.0	0.8	0.0	0.6	0.6	0.0
# 13	3	0.3	0.1	0.4	0.4	1.1	0.1	0.8	0.6	0.8	0.7	1.2	0.0
	14	1.0	0.2	1.4	0.1	1.1	0.1	1.0	0.4	1.4	0.0	0.5	0.4
# 14	3	1.1	0.1	1.1	0.1	0.9	0.1	1.4	0.5	1.5	0.4	0.8	0.0
	14	2.3	0.1	1.7	0.2	0.8	0.1	0.9	0.2	1.0	0.0	1.6	0.0
# 15	3	2.6	0.7	0.3	0.8	3.1	0.4	3.6	1.1	0.4	1.7	2.4	0.9
	14	0.1	0.9	0.1	0.2	0.8	0.2	0.4	1.2	1.4	0.4	0.6	0.7
# 16	3	*	*	*	*	*	*	*	*	*	*	*	*
	14	0.1	0.2	0.1	0.1	0.1	0.1	0.0	0.6	0.0	1.3	0.0	0.6
# 17	3	0.2	1.8	0.3	2.0	1.0	0.1	1.0	3.9	0.8	2.3	1.0	0.0
	14	0.2	3.4	0.2	3.2	0.7	0.1	0.8	12.5	0.4	3.7	0.8	0.0
# 18	3	0.1	7.5	0.2	6.5	0.7	8.2	0.4	9.2	0.0	7.2	0.8	7.8
	14	0.1	1.3	0.3	1.4	0.4	2.8	0.0	3.6	0.6	1.1	0.8	3.6

Table 2. Data table page 1.

Maxillary Sinus Data **Page 2 of 2**

Specimen	Tooth	Caliper measurement						Cone beam measurement					
		Mesial buccal		Distal buccal		Palatal		Mesial buccal		Distal buccal		Palatal	
		Facial	Sinus	Facial	Sinus	Lingual	Sinus	Facial	Sinus	Facial	Sinus	Lingual	Sinus
# 19	3	0.7	2.1	2.7	1.3	2.7	0.5	0.3	2.3	2.8	2.3	2.0	0.9
	14	0.7	1.1	3.1	0.6	2.9	0.2	1.4	2.3	3.5	0.9	2.2	0.6
# 20	3	0.1	16.3	2.5	7.2	0.3	14.5	0.0	15.5	2.2	10.5	0.3	14.5
	14	0.2	0.6	0.4	1.9	0.5	1.9	0.4	0.9	0.2	2.7	0.4	2.0
# 21	3	0.9	0.2	2.1	0.1	3.1	0.5	1.4	0.1	2.5	0.0	1.5	0.7
	14	1.0	0.2	1.9	0.4	1.4	0.2	1.0	0.6	2.2	0.8	0.8	0.0
# 22	3	0.5	0.4	0.3	0.2	2.2	0.3	0.4	0.9	0.5	0.9	1.0	0.0
	14	0.3	0.2	1.9	0.4	0.9	0.2	0.4	0.5	2.0	0.0	0.8	0.0
# 23	3	0.4	1.4	1.1	2.0	2.6	0.6	1.8	4.4	1.8	3.7	1.7	1.0
	14	1.3	1.1	0.6	0.5	1.6	0.2	2.2	2.9	1.6	2.3	0.9	0.8
# 24	3	0.1	2.6	0.1	3.0	0.4	1.6	1.1	4.4	0.0	3.4	0.0	2.4
	14	*	*	*	*	*	*	*	*	*	*	*	*
# 25	3	0.8	0.3	3.2	0.2	1.8	0.4	1.0	0.4	2.8	0.0	2.2	0.2
	14	0.7	0.4	3.3	0.2	2.6	0.7	0.6	0.0	2.2	4.8	5.4	0.6
# 26	3	0.1	0.2	0.3	0.1	0.3	0.2	0.0	0.3	0.2	0.0	1.0	0.0
	14	0.0	0.3	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.3	0.3	0.3
# 27	3	1.2	0.2	0.7	0.5	1.6	0.3	0.9	0.0	0.2	0.6	0.6	0.0
	14	0.8	0.1	0.3	0.4	0.9	0.4	0.0	1.0	1.2	1.0	1.1	0.0
# 28	3	1.8	0.5	2.2	0.8	0.6	0.3	1.4	0.4	3.6	0.0	0.6	1.0
	14	*	*	*	*	*	*	*	*	*	*	*	*
# 29	3	0.7	0.2	0.9	0.1	0.4	1.5	0.6	0.8	0.0	0.7	0.0	1.9
	14	0.2	0.2	0.5	0.2	1.4	0.2	0.8	0.0	0.6	0.0	1.2	0.0
# 30	3	2.1	0.5	0.9	1.8	1.0	0.5	2.4	1.9	1.4	2.3	0.8	0.6
	14	0.6	0.3	0.2	1.8	1.0	0.2	1.0	1.8	1.3	1.9	1.2	0.0
# 31	3	0.2	6.2	1.6	2.5	3.3	1.5	0.0	8.2	2.4	3.4	3.2	2.0
	14	0.3	4.6	1.3	3.0	1.6	2.0	0.0	7.8	1.2	3.3	1.6	2.2
# 32	3	0.9	0.5	3.8	0.8	3.2	0.5	1.0	2.8	2.6	2.8	2.6	0.6
	14	0.3	0.2	0.6	0.3	0.7	0.2	0.0	2.6	0.3	1.1	0.6	0.7
# 33	3	0.2	1.0	0.2	0.6	2.3	0.4	0.0	1.5	0.7	1.0	2.0	1.0
	14	0.2	0.9	1.3	0.7	2.2	0.4	0.2	1.6	1.2	1.3	2.0	0.8
# 34	3	*	*	*	*	*	*	*	*	*	*	*	*
	14	0.6	1.4	0.1	2.0	1.4	1.2	0.1	3.3	0.2	2.6	1.1	1.3
# 35	3	0.3	1.0	0.1	1.5	2.3	0.2	0.2	1.6	0.0	1.8	2.8	0.7
	14	0.2	0.3	0.2	0.2	1.8	0.2	0.0	3.4	0.0	1.6	2.4	0.5
# 36	3	0.8	1.4	0.9	1.2	0.8	0.3	0.0	2.0	1.0	1.3	0.7	0.7
	14	0.3	0.2	0.2	0.2	0.6	0.5	0.6	0.6	1.8	0.9	0.3	1.0
# 37	3	1.6	0.2	0.7	0.4	0.8	0.3	1.5	0.1	0.5	0.7	0.8	0.3
	14	0.7	0.4	0.4	2.0	1.1	0.8	0.8	0.8	0.2	2.8	0.8	1.1

Table 3. Data table page 2.

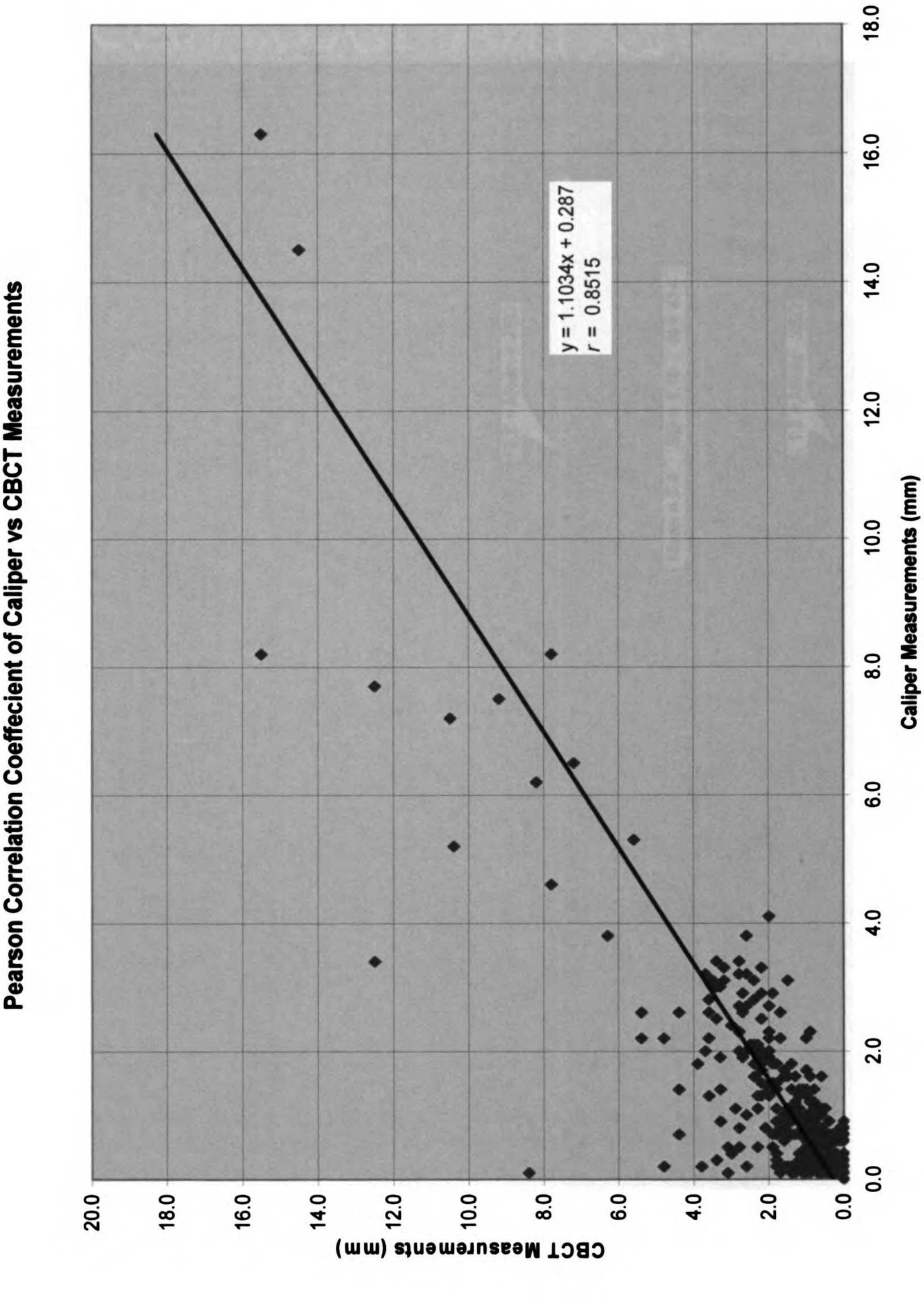


Figure 3. Pearson correlation coefficient of caliper vs. CBCT measurements.

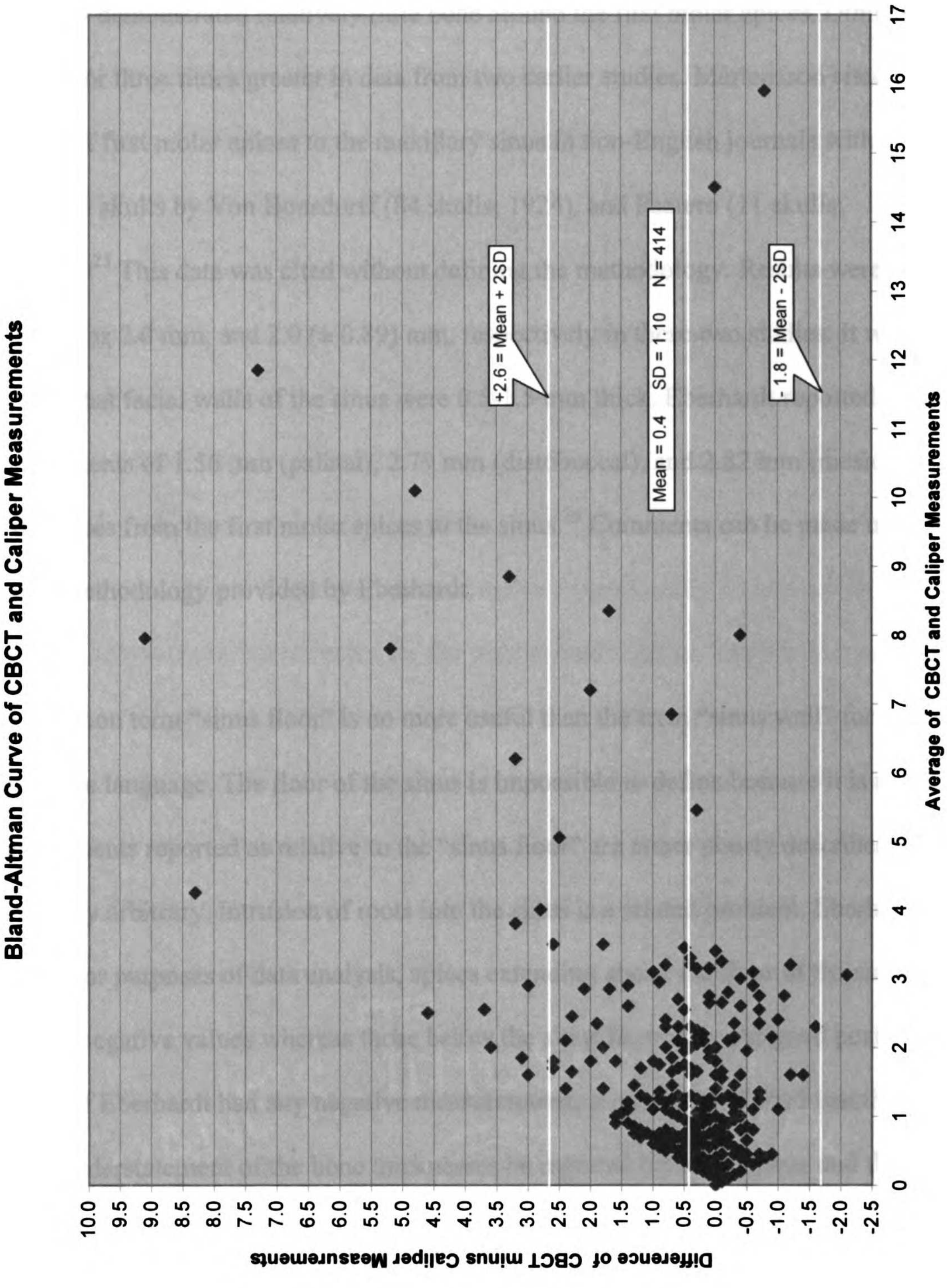


Figure 4. Bland-Altman curve of CBCT and caliper measurements.

Discussion

This study demonstrated relatively little bone around the first molar apices. Dimensions were two or three times greater in data from two earlier studies. Mårtensson cited the distance of first molar apices to the maxillary sinus in non-English journals with studies on Finnish skulls by Von Bonsdorff (84 skulls; 1924), and Paatero (11 skulls; 1939).[23,24,25] This data was cited without defining the methodology. Results were presented as 2.6 mm, and 2.0 (± 0.89) mm, respectively in these two studies. It was also reported that facial walls of the sinus were 0.5-1.5 mm thick. Eberhardt reported average measurements of 1.56 mm (palatal), 2.79 mm (distobuccal), and 2.82 mm (mesiobuccal), for distances from the first molar apices to the sinus.[26] Comments can be made upon the limited methodology provided by Eberhardt.

The common term "sinus floor" is no more useful than the term "sinus wall" for general descriptive language. The floor of the sinus is impossible to define because it is not flat. Measurements reported as relative to the "sinus floor" are either poorly described, or completely arbitrary. Intrusion of roots into the sinus is a related problem. Eberhardt stated: "For purposes of data analysis, apices extending above the floor of the sinus were assigned negative values whereas those below the sinus floor were assigned positive values." If Eberhardt had any negative measurements, it can be concluded that this caused understatement of the bone thicknesses he reported between apices and the sinus. What if the root apex was in the sinus wall above the sinus floor as is often the case for a first molar? Intrusion into the sinus implies nothing about the dimension of bone covering the root apex. The minimum distance of bone between a root apex and the sinus is the only valid, and clinically useful, concept of measurement. If the maxillary posterior teeth are stable longitudinal landmarks in the dentate human, then pneumatization of the maxillary sinus could be studied in relation to age with the kind of data in this study, in conjunction with the volumetric analysis tools that CBCT can utilize for a hollow space like the maxillary sinus.

The age of specimens and subjects is unreported in the above studies. The mean age at time of death for specimens in this study was 76 years (± 15.6 SD). Eberhardt utilized 38-archived tomography scans of human subjects and 12 cadaveric specimens.[26] He may have studied a younger population. The studies cited by Mårtensson took place in the 1920's when cadaveric demographics may have been significantly different.[23,24,25] Over five years, specimens were collected for the present study. About half of observed cadavers were edentulous, and about one-third of the dentate cadavers were accepted as specimens. Observations by gross anatomists suggests that the numbers of dentate cadavers has greatly increased in the last fifteen years. Further research may determine that maxillary sinus pneumatization extends long past early adulthood. This is contrary to accepted conclusions in the literature.[1,13]

Another detail of methodology may account for greater measurements by Eberhardt. His data was collected with a scan thickness of 1.5 mm whereas the CBCT scans of the present study were 0.2 mm in section thickness. If a root apex were 3.0 mm thick, then Eberhardt's scans might produce two views of the root whereas CBCT could provide fifteen views. Each view will be related to voxel size, and will display the maximum dimension of bone present in the reconstructed image plane thickness . This is significant. The experience of manual dissection demonstrated that the data was sensitive to slight variations of caliper placement. In the additional literature cited above, scan plane thicknesses were 1.0 mm, 1.2 mm, and 1.3 mm, respectively.[27,28,29]

Christiansen studied intraobserver and interobserver variability and accuracy in the determination of linear and angular measurements in computed tomography on human mandibles *in vitro* and *in vivo*.[32] Likewise, Eberhardt's study of human subjects and cadaveric specimens reportedly examined this issue. No statistically significant differences were reported in either of these studies between the values measured *in vitro* or *in vivo*. Two studies cited below found that intraobserver measurements were highly reliable.[33,34] In the present study, all the manual dissections and caliper measurements were performed by the author. The tomographic analysis was divided in half between the author and a faculty member in gross anatomy familiar with the project. No significant difference was found in correlations of scores between the two observers in the tomographic analysis.

High dimensional accuracy has been reported for CBCT in measurement of facial structures.[14,33-39] Caliper measurement of dried bone represents a tested historical gold standard in anatomy and anthropology. Moshiri examined 23 dried skulls in 2007.[34] He compared caliper measurements to traditional lateral cephalography and three methods for simulating lateral cephalograms with CBCT in evaluation of standard anthropometric landmarks common to orthodontic diagnosis. His paper concluded that no single imaging technique provided accurate representation of all osseous aspects of the craniofacial region, but that CBCT images were the most accurate overall. In 2005, Hilgers tested CBCT accuracy of linear measurement against anatomic truth in the TMJ areas of 25 human skulls, and concluded that CBCT data was accurate and reliable.[33] Recently, Stratemann compared the accuracy of caliper measurements on a single skull embedded with steel balls at 32 cranial and 33 mandibular landmarks against two different CBCT systems, the NewTom and the CB MercuRay.[14] The study concluded that both CBCT systems provided highly accurate data compared to physical measurement with less than 1% relative error. The CB MercuRay system was evaluated as slightly more accurate. It is noteworthy that the present study was conducted on the same CB MercuRay unit as the Stratemann study. Further, the present study represented a logical progressive step of research methodology that compared one real clinical method of anatomical measurement to another. Caliper measurement of non-dried bone is credible data comparable to the historic gold standard of dried bone measurement.

The Bland-Altman approach has been used extensively to compare two clinical measures. The authors made the observation that two methods of measurement can be in perfect correlation when grossly out of agreement. They also pointed out that calibration is a different problem than comparison of two methods of measurement presumed to be equally good or bad. The measurement problem presented in this study may lie between these ends of this spectrum. The manual gross dissection caliper measurements presented in this study are difficult to describe and perform in a universally consistent matter. To be sure, problems ensued in attempts to measure porous and greasy embalmed bone.

However, the study proposes that any surgeon would trust direct caliper measurements of surgical site dimensions. To this end, the CBCT measurements were evaluated for correlation as well as agreement relative to gross anatomic dissection. Although the data included outliers as seen on Figure 3 and Figure 4, the majority of data points were less than 3.0 mm, and a smaller range substantiates correlations.

The Bland-Altman analysis in this study suggested CBCT measurements were overstated by 0.4 mm, but that 66% were within 1.1 mm standard deviation (SD) of accuracy obtained by invasive manual caliper measurements. 96% of CBCT measurements were accurate within 2.2 mm SD. The operational definition of accuracy could be made relative to the wound size induced by a surgical bur, because this is the minimum dimension required by a surgeon working in a bony field. This wound is 2-3 mm in width and operationally defined as 2.5 mm in the present study. A #6 round bur is a smaller surgical bur that is 1.9 mm in diameter, which will create a somewhat larger wound with manipulation. A common larger bur is the #8 round bur which is 2.6 mm in diameter.

As stated in the introduction, the morphology of the maxillary sinus is variable. The present study is in agreement that septa generally housed tooth roots and occur with frequency and location as other studies indicate. Studies are fairly unanimous in concluding that the second molar most closely approximates the sinus. This conclusion seemed reasonable, and the second molar quite often had more fused roots which are located in a convexity that protrudes into the sinus from its facial wall, and these protrusions were usually directly in line anterior-posteriorly with the palato-maxillary suture. While the bone in this region is thin, a trans-antral approach to the palatal root apex in surgical procedures would not be likely. This is in contrast to the first molar which frequently exhibits a "fossa interradicularis" that would entail a deep surgical trans-antral approach from the buccal to reach the palatal apex in the lingual wall of the sinus. Palatal apices of the first molar were usually situated 1 cm from the greater palatine foramen with the greater palatine artery coursing forward toward these apices. This would make a palatal approach a significant challenge for practitioners who do not engage in surgical procedures routinely.

In almost all cases, some layer of bone was found to overlie radicular surfaces from visual inspection of the dissected materials. This layer was often seen to be a nearly invisible film of non-measurable thickness. A complete lack of bone over radicular surfaces was observed occasionally in cases exhibiting multiple signs of severe and extensive endodontic pathology.

Two additional observations should be considered. First, the maxilla around the sinus appeared to be an eggshell structure. Second, to the extent that the sinus floor was below the transverse plane of palatal vault, this thin-structure characteristic was enhanced. Above the horizontal plane of the palatal vault, the medial sinus wall adjoined the nasal passages, and the lateral wall was buttressed by the zygomatic arch. When the sinus extended deeply inferior to the level of the palate, to the detriment of solid alveolar bone, greater pneumatization led to thinner sinus walls adjoining the oral cavity. In these cases root eminences were more frequently visible in the sinus along with increased presence of the interradicular fossa mentioned above. These thin sinus walls were usually 0.5-1.5 mm thick with a strong tendency toward the minimum. This relationship would favor increased oral access to the sinus for procedures such as hydraulic sinus lift technique.

The greatest problem encountered in this study was scatter interference (i.e., flare) caused by metal restorations in the teeth of the specimens. Generally, CBCT is especially tolerant of metal in the scanning field, so it is useful for visualizing the head and neck when dental restorations are present. Zhang, in 2007, reported good success with implementation of an effective metal artifact-suppressing algorithm that improved the quality of CBCT images.[40] However, in this study, the presence of scatter interference appeared to be associated with scanning date. Earlier scans exhibited more interference making specimens difficult to score.

Conclusion

The present study compared two identical data sets of 414 measurements in which each were obtained by two different methods. The method of collecting the first data set was gross manual dissection and measurement with physical calipers. The method of collecting the second data set used digital radiographic images from cone beam computed tomography scans. The data sets were compared utilizing the Pearson product-moment correlation coefficient (r) and Bland-Altman statistics for comparing methods of measurement. The data sets were found to be related at a high level of positive correlation ($r = 0.85$). The CBCT data set was found to have a positive bias of 0.4 mm and a Difference of Measurement standard deviation of 1.1 mm. Thus, 96% of all CBCT measurements should be correct within 2.2 mm of the true dimension.

An operational definition of clinical accuracy was accepted to be 2.5 mm. This was justified on the basis that the minimum wound size created by a small surgical bur can represent a reasonable dimension of acceptable clinical accuracy in a bony field.

The present study accepts the accuracy of CBCT for valid measurement of maxillary bone around posterior root apices, and for general study of the maxilla. CBCT provides a great advantage in obtaining data non-invasively. Further, CBCT data can provide volumetric analysis that would be useful for the study of the maxillary sinus in the future.

The present study achieved many valuable goals. The study identified unresolved issues in this area of anatomical research, and demonstrated a lack of information on this subject. Study methods were presented more completely than in other studies available. Results indicate that sinus pneumatization may be a dynamic process throughout adult life in contrast to commonly published opinion. This process could express major significance to implant placement and longevity in the maxillary posterior region.

Importantly, the present study validated the need for further research in this important area of anatomy and dentistry. It served to establish the protocol for study of human subjects through preliminary study of cadaveric specimens. The study indicated a need to validate long-term stability of maxillary posterior roots and the palatal vault as radiographic cranial landmarks. Finally, the study laid a basis to utilize information that

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