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Comparison of Maxillary Sinus Dimensions and Volumes on CBCT and 3T MR Images

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Comparison of Maxillary Sinus Dimensions and Volumes on CBCT and 3T MR Images

by

Cara Hodgson

A Thesis submitted in partial satisfaction of
the requirements for the degree
Master of Science in Orthodontics and Dentofacial Orthopedics

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Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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ABBREVIATIONS

3D	Three-dimensional
CBCT	Cone Beam Computed Tomography
MR	Magnetic Resonance
TMJ	Temporomandibular Joint
3T	3-Tesla
2D	Two-dimensional
CT	Multi-detector Computed Tomography
ALARA	As Low As Reasonably Achievable
ADA	American Dental Association
AAO	American Association of Orthodontists
AAOMR	American Academy of Oral and Maxillofacial Radiology
ICRP	International Commission of Radiological Protection
IRB	Institutional Review Board
LLUSD	Loma Linda University School of Dentistry
FOV	Field of View
DICOM	Digital Imaging and Communications in Medicine
MP-RAGE	Magnetization Prepared Rapid Acquisition by Gradient Echo
ANS	Anterior Nasal Spine
PNS	Posterior Nasal Spine
ICC	Intraclass Correlation Coefficient
LLUMC	Loma Linda University Medical Center

ABSTRACT OF THE THESIS

Comparison of Maxillary Sinus Dimensions and Volumes on CBCT and 3T MR Images

by

Cara Hodgson

Master of Science, Graduate Program in Orthodontics and Dentofacial Orthopedics
Loma Linda University, September 2019
Dr. V. Leroy Leggitt, Chairperson

Objective: This study compared the height, width, length, and volume of the maxillary sinus in Magnetic Resonance Imaging (MRI) and Cone-Beam Computed Tomography (CBCT).

Methods: Eleven human subjects participated in the study (mean age of 14y7m). One CBCT scan and one MRI scan were performed on each patient. CBCT images were captured with an 18 x16 inch field of view that covered the whole head. Contiguous sagittal MR images of the whole head were produced using a 3.0T imaging system with a T1-weighted 3D imaging sequence and isotropic resolution of 1.0 x1.0 x1.0 mm. Images were imported as DICOM files into Simpleware Scan IP (v.2018-03), and registered in three planes of space. CBCT and MRI were measured and segmented separately. Volume was calculated using a 3D model of the sinuses. Maxillary sinus height, width, length were measured on the un-segmented digital images. Statistical analysis was performed by using Intraclass correlation coefficient (ICC) and by generating Bland-Altman plots. All tests of hypotheses were two-way and conducted at an $\alpha = 0.05$ using SPSS (Chicago, IL).

Results: The results indicate excellent agreement between CBCT and MRI measurements. Mean Intraobserver ICC were 0.999 - 1.000 for CBCT and 0.993 - 0.998 for MRI. Average ICC to assess agreement between CBCT and MRI were 0.991-0.997. There was no statistically significant systematic bias when comparing CBCT and MRI measurements ($p > 0.05$) for all but one measurement. There was a systematic bias of $1.27cm^3$ ($p = 0.016$) for the left MRI maxillary sinus volume.

Conclusion: Measurements of the maxillary sinus made on MRI are in good agreement with equivalent CBCT measurements. These results indicate that further studies are warranted to characterize the interchangeability of CBCT and MRI for the purpose of maxillary sinus analysis. MRI could be an attractive alternative to CBCT because it does not expose patients to ionizing radiation, and is the highest contrast resolution medical imaging technique

CHAPTER ONE

REVIEW OF THE LITERATURE

Imaging plays an important role in the treatment of an orthodontic patient. There are multiple points in time when images are required, including prior to initiating treatment to improve treatment planning, during treatment to assess progress, and at the completion of treatment to assess the final outcome. Orthodontic and dentofacial orthopedic diagnosis and treatment planning has relied on two-dimensional (2D) planar radiographic imaging and cephalometry for nearly a century.[1] Traditionally these images included lateral cephalograms, panoramic radiographs, and full mouth surveys consisting of multiple periapical and bitewing radiographs. Acquiring these images provides practitioners with the necessary information concerning the hard and soft facial tissues and the dentition in order to make decisions regarding treatment modalities. There are several disadvantages of using 2D imaging techniques, with the most significant being that it reduces a three-dimensional (3D) object to a 2D view. In doing so, tissue overlapping, landmark obstruction, distortion, magnification and object displacement occur.[2,3,4] Recognizing the importance of comprehensive visualization of craniofacial structures in orthodontics initiated the trend towards 3D imaging technologies.[2,5,6]

Cone beam computed tomography (CBCT) was introduced to the dental field over two decades ago and has become the most widely used form of 3D imaging technology in orthodontics today.[5] CBCT technology allows the orthodontist to overcome previous challenges involved with extrapolating 3D information from a 2D image, especially in cases involving impacted teeth, airway, temporomandibular joint disorders, asymmetries, and other craniofacial complexities.[5,7,8] While it is widely accepted how useful these images are in diagnosis and treatment planning, CBCT exposes the patient to ionizing radiation. Although the amount of exposure can be adjusted based on the manufacturer and CBCT unit settings, radiation exposure to orthodontic patients is becoming a major concern.[1,6,9] A well-known, long-term effect of ionizing radiation is an increased stochastic risk of radiation-induced carcinogenesis.[1] This increased risk of carcinogenesis could be avoided using a radiation-free imaging technique such as magnetic resonance imaging (MRI).

Magnetic resonance imaging (MRI) is 3D imaging technology that does not expose patients to ionizing radiation, and it is the highest contrast resolution medical imaging technique. [2] MRI is commonly used in the medical field to diagnose various pathologies and conditions. A study done by Gray et al. concludes that MRI should replace CBTC when possible and has often been employed by dental professionals to investigate temporomandibular joints, nerves, and soft tissue pathologies such as tumors.[10] MR images provide visualization of both hard and soft tissue structures, and allow the provider to distinguish between adjacent soft tissues. Images are obtained with radiofrequency (RF) radiation in the presence of carefully controlled magnetic fields.[11] The MR device measures changes in the resonance signal and magnetic moment of hydrogen nuclei (protons) in body tissues, bone and fat, each of which has a different density than water.[2,11] These differences are processed by a computer and converted into an image. The differential densities of protons and the molecular environment influence the relative intensities of the MR signal generated, thus distinguishing different tissues. MR imaging sequences can be divided into two groups: T1- weighted or T2-weighted. T1-weighted have a longitudinal proton relation time, and T2-weighted have a transverse proton relation time.[10] The contrast difference between the two types enables the T1-weighted image to depict normal anatomy, while T2-weighted images are used to detect infection, hemorrhage, and tumors.[10]

Although certain instances of pathology, such as the presence of oral cancer, require T2-weighted images, typical orthodontic diagnosis can be completed using T1-weighted images to assess normal anatomy. In T1-weighted images, the external cortical plate appears black, unlike traditional radiographs, where the increased bone density appears radio-opaque.[10] The MRI appearance is due to an absence of water or lipid protons in cortical bone, which produces a low signal during MR imaging. Conversely, the high concentration of protons in the fatty bone marrow of cancellous bone creates a strong signal and appears very bright in T1-weighted images. Nerves are identified on MR images by distinguishing between the distinct dark neurovascular channels within the bright cancellous bone. Understanding how to identify these tissues enables the user to view and measure the jaw bones. The appearance of soft tissues on MR images also differs from conventional radiographs due to superior soft-tissue contrast. “It appears as a white to grey mid-level signal in T1-weighted scans, and provides information on tissue contour and thickness, and shape of mucous on the alveolar ridge.”[10,12] Soft tissues are easily detected on MR images because of their high density of hydrogen atoms. The ability of MRI to distinguish among soft tissues, makes it the gold standard for imaging the TMJ. Valuable information about the position and morphology of the disk can be acquired using MRI, while CBCT does not provide this information.[2]

As with any imaging technique, MRI presents certain disadvantages, including increased cost, longer imaging times, unavailability in all medical centers and dental offices, poorer visualization of hard tissues, and metal-induced image distortions. The teeth transmit a very low signal on T1-weighted images and appear black, making them more difficult to distinguish on the image. Contraindication of MRI include patients with claustrophobia, cardiac pacemakers, implanted cardiac defibrillators, metallic foreign bodies in the eyes, retained ferromagnetic surgical clips, or patients in the first trimester of pregnancy.[2,10,13] A full medical history should be taken prior to an MRI scan to avoid harming the patient.

Evaluating the dimensions of the maxillary sinuses is an integral part of orthodontic diagnosis and treatment planning especially when mini implants are placed or orthognathic surgery is planned. Since the majority of orthodontic patients are children and adolescents, orthodontists frequently are the first to evaluate whether a patient is a mouth breather, as well as find pathology in the sinus. Orthodontists are also frequently the first to refer the patients to an otolaryngologist for treatment. Oral breathing has a prevalence of over 50% among children and is regarded as a pathological condition that can cause problems such as changes in orofacial muscle tone, dry mouth, occlusal changes, chewing and swallowing pattern deviations, dental caries, periodontal diseases, and speech and sleep disorders.[14] Therefore, it is imperative that orthodontists evaluate all of the craniofacial structures in the scans taken for any signs of mouth breathing or pathology in the sinus. Farid et al. found that 77% of mouth breathers had maxillary sinusitis, and Tikku et al. concluded that the mean maxillary sinus volume of mouth breathers was significantly less than normal breathers, indicating that orthodontists need to be able to clearly evaluate the maxillary sinus dimensions during diagnosis and treatment planning.[15,16]

Evaluating a patient's face type is one of the most valuable pieces of information when diagnosing and treatment planning a case in orthodontics. Oksayan et al. evaluated the maxillary sinus volumes and dimensions in different vertical face growth patterns, and the high angle subjects showed statistically lower values for maxillary sinus length and width than low angle subjects.[17] Therefore evaluating the length, width, and volume of the maxillary sinuses will be useful when planning orthognathic surgery and orthodontic mini screw application in different vertical face patterns.[17] The dimensions of the maxillary sinus are also affected when maxillary expansion is used. Garrett et al. evaluated the skeletal effects to the maxilla after rapid maxillary expansion using CBCT and discovered that it produces a statistically significant decrease in maxillary sinus width.[18] The age-related changes in maxillary sinus diameters were studied in relation to diameters of the facial skeleton and all measurements of maxillary sinuses correlated with midface dimensions. The maxillary sinus is present at birth and increases in size until the 18th year, growing in the anterior posterior, vertical and horizontal directions.[19] Understanding the age-related changes in the dimensions and the volume of the normal maxillary sinus can help identify sinus abnormalities. In Detterbeck's study comparing the usefulness of MRI in clinical orthodontic applications, images from MRI scans compared favorably to the same images created from conventional CT scans. However, there is a need to explore the opportunities for radiation-free 3D diagnostics in the orthodontic field with further studies.[20]

The purpose of this study is to determine if 3-Tesla (3T) MR scans are in agreement with measurements of the height, width, length, and volumes of maxillary sinuses compared to CBCT scans. If so, exposure to ionizing radiation may be decreased through utilization of MR images to perform orthodontic diagnosis, and thus, minimizing the risk of radiation induced carcinogenesis.

CHAPTER TWO

COMPARISON OF MAXILLARY SINUS DIMENSIONS AND VOLUMES ON CBCT AND 3T MR IMAGES

Abstract

Objective: This study compared the height, width, length, and volume of the maxillary sinus in Magnetic Resonance Imaging (MRI) and Cone-Beam Computed Tomography (CBCT).

Methods: Eleven human subjects participated in the study (mean age of 14y7m). One CBCT scan and one MRI scan were performed on each patient. CBCT images were captured with an 18x16 inch field of view that covered the whole head. Contiguous sagittal MR images of the whole head were produced in a 3.0T imaging system with a T1-weighted 3D imaging sequence and isotropic resolution of 1.0x1.0x1.0mm. Images were imported as DICOM files into Simpleware Scan IP (v.2018-03), and registered in three planes of space. CBCT and MRI were measured and segmented separately. Volume was calculated using a 3D model of the sinuses. Maxillary sinus height, width, length were measured on the un-segmented digital images. Statistical analysis was performed by using Intraclass correlation coefficient (ICC) and by generating Bland-Altman plots. All tests of hypotheses were two-way and conducted at an alpha level of 0.05 using SPSS (Chicago, IL).

Results: The results indicate excellent agreement between CBCT and MRI measurements. Mean Intraobserver ICC were 0.999 -1.000 for CBCT and 0.993-0.998 for MRI. Average ICC to assess agreement between CBCT and MRI were 0.991-0.997. There was no statistically significant systematic bias when comparing CBCT and MRI measurements ($p>0.05$) for all but one measurement. There was a systematic bias of $1.27cm^3$ ($p=0.016$) for the left MRI maxillary sinus volume.

Conclusion: Measurements of the maxillary sinus made on MRI have very good agreement with equivalent CBCT measurements. These results indicate that further studies are warranted to characterize the interchangeability of CBCT and MRI for the purpose of maxillary sinus analysis. MRI could be an attractive alternative to CBCT because it does not expose patients to ionizing radiation, and is the highest contrast resolution medical imaging technique

Introduction

As CBCT use in orthodontics has increased, concern regarding radiation dose to the patient has been amplified. Since ionizing radiation is linked to an increased risk of cancer, it is crucial to minimize exposure.[21] This is especially important in young patients where the radio-sensitivity of proliferating tissues is magnified. Radiation risk is estimated using the effective dose.[1] The effective dose is calculated by multiplying the equivalent dose with a weighting factor defined by the International Commission on Radiological Protection (ICRP) for each organ. The effective dose for each organ can be summed together to obtain the total effective dose.[9] The effective dose for CBCT ranges from 58.9 to 1073 microsieverts.[6,22,9] It differs between CBCT units and is closely related to the exposure parameters used for scanning. CBCT provides an accurate assessment for examining maxillary sinuses, and many other craniofacial structures needed for orthodontic diagnosis and treatment planning. However, there is increasing awareness that ionizing radiation is linked with an increase in cancer risk, especially in growing children. This has led to the adoption of the ALARA (As Low As Reasonably Achievable) principle in dental radiology, which requires the clinician to make a decision after analyzing the risks and benefits together for each individual patient.[9,22]. By using MR imaging to collect the 3D data necessary for orthodontic diagnosis instead of CBCT, the ALARA principle is satisfied.

Often, CBCT scans are supplemented with traditional radiographs, such as panoramic radiographs, lateral cephalograms, and full mouth series, thus adding to the already significant radiation exposure. The effective dose for a panoramic radiograph ranges from 3.86-38.0 μSv, for a lateral cephalogram is 1.1-5.6 μSv, for a posteroanterior cephalogram is 5.1 μSv, and for one full mouth X-ray is 0.65-9.5 μSv.[9] The significantly higher radiation exposure with CBCT compared to traditional radiographs is important considering the age of the majority of orthodontic patients.

In this proposed study, the aim is to compare the height, width, length, and volumes of maxillary sinuses in MRI versus CBCT to determine if 3T MRI can be used to measure the maxillary sinuses as accurately as CBCT. Evaluating the maxillary sinus is an integral part of the diagnostic and treatment planning process in orthodontics. Since the majority of orthodontic patients are children and adolescents, part of the diagnosis and treatment planning of patients is to assess all of the craniofacial structures in the scans taken. Orthodontists are in a primary position to screen patients for various pathologies of the maxillary sinus and refer them to an otolaryngologist as needed.[23] The precise assessment of the maxillary sinus is important, especially in cases involving sinusitis, the presence of sinus polyps, mucosal thickening, mucoceles, mini implant placement, and in planning orthognathic surgery. When planning orthognathic surgery, moving teeth, and placing mini-implants near the maxillary sinus, it is crucial to know the dimensions of the maxillary sinuses. A patient's face type also affects the length and width of the maxillary sinuses, therefore accurately measuring the dimensions of maxillary sinuses may help determine face type.[17] Face type is one of the most important factors in orthodontic diagnosis and treatment planning, especially when deciding to treat a case with extractions versus no extractions.[17]

Establishing that linear and volumetric measurements of the maxillary sinuses can be successfully made from MRI scans is a step toward showing that orthodontic diagnosis may be performed on MRI. If a strong agreement between measurements of the maxillary sinus on CBCT and MRI is found, this can substantiate the notion that other length, volume, and angle measurements required for orthodontic diagnosis can be obtained using MRI and applied in orthodontic treatment planning. Replacing CBCT with MRI for orthodontic diagnosis would eliminate exposure to ionizing radiation altogether as advocated by the ALARA principle and may provide better soft-tissue contrast.

Materials and Methods

Eleven human subjects participated in this study, each being a new patient at the Loma Linda University School of Dentistry (LLUSD) graduate orthodontics clinic. Patients were excluded from the study based on several criteria. Exclusion criteria included the presence of: 1) metal dental restorations, 2) dental implants, 3) fixed orthodontic appliances, 4) removable orthodontic appliances, 5) pacemakers, 6) cochlear implants, 7) metal foreign bodies in the eyes, 8) aneurysm clips, 9) prosthetic metal implants, and 10) pregnancy. The patients' age ranged from 12 years and 1 month to 31 years and 5 months (mean age 14 years and 7 months).

One CBCT scan (NewTom 5G, AFP Imaging, USA) and one 3T MR scan (Siemens Medical Solutions, DE) without intraoral contrast media was performed on each subject. All scans were performed within two weeks of one another, prior to the placement of orthodontic separators or appliances. CBCT images were acquired with a 18 x16 inch field of view that covered the entire head. Contiguous sagittal MR images of the whole head were created in a 3.0T imaging system with a T1-weighted 3D imaging sequence (Magnetization Prepared Rapid Acquisition by Gradient Echo (MP-RAGE), TR/TE = 1950/2.26 ms) and isotropic resolution of 1.0 x1.0 x1.0 mm. Scan time was less than 4 minutes. Digital Imaging and Communications in Medicine (DICOM) formatted images were constructed from both scans and the volumes were oriented in all three planes. Volumes were oriented from the frontal view (coronal plane) such that a line connecting the lower rim of each orbit was parallel to the horizon. Next, volumes were oriented in the transverse plane so a line connecting the widest points of the maxillary sinuses were parallel to the horizon. Lastly, the volumes were oriented in the sagittal plane such that a line connecting the anterior nasal spine (ANS) to posterior nasal spine (PNS) was parallel to the horizon.

The height, width, length, and volumes of the maxillary sinuses in each CBCT and MRI were measured and calculated, then were compared to see if the measurements made on MR scans were in agreement with the measurements made on CBCT scans. The three linear measurements (height, width, length), were made on the axial and coronal cross sections, where the longest distances could be measured between the points AR-PR, AL-PL, SR-IR, SL-IL, LR-MR, and LL-ML.[24] (Table 1)

Table 1. Definitions of the maxillary sinus landmarks used for measurements.

Point	Name	Description
AR	Anterior point of the Right maxillary sinus	most anterior point of the right maxillary sinus in all the images.
AL	Anterior point of the Left maxillary sinus	most anterior point of the left maxillary sinus in all the images.
PR	Posterior point of the Right maxillary sinus	most posterior point of the right maxillary sinus in all the images.
PL	Posterior point of the Left maxillary sinus	most posterior point of the left maxillary sinus in all the images.
SR	Superior point of the Right maxillary sinus	most superior point of the right maxillary sinus in all the images.
SL	Superior point of the left maxillary sinus	most superior point of the left maxillary sinus in all the images.
IR	Inferior point of the Right maxillary sinus	most inferior point of the right maxillary sinus in all the images.
IL	Inferior point of the Left maxillary sinus	most inferior point of the left maxillary sinus in all the images.
LR	Lateral point of the Right maxillary sinus	the most lateral point on the lateral process of the right maxillary sinus
LL	Lateral point of the Left maxillary sinus	the most lateral point on the lateral process of the left maxillary sinus
MR	Medial point of the Right maxillary sinus	The most medial point on the medial wall of the right maxillary sinus
ML	Medial point of the Left maxillary sinus	The most medial point on the medial wall of the left maxillary sinus

Height was measured away from the inner surface of the anterior border of the maxillary sinus and was defined as the longest distance between the most inferior point of the maxillary sinus floor to the highest point of the sinus roof in the coronal view (SR-IR and SL-IL), after scrolling through all the images and there was an agreement in all the views. (Fig. 1)

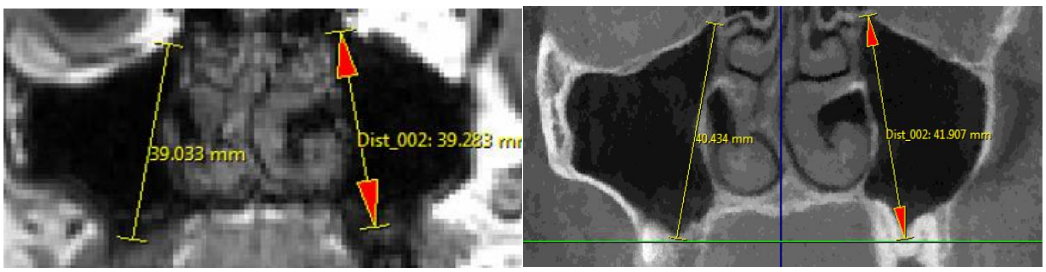

Figure 1. Measurement of the height of the maxillary sinuses. Shown here are right and left maxillary sinuses on CBCT slice (right) and MRI slice (left).

Width was measured at the largest part of the sinus in the transverse plane, and was defined as the longest distance between the most medial point of the maxillary sinus and the most lateral point of the lateral process of the maxillary sinus calculated in the axial view (MR-LR and ML-LL), after scrolling through all the images and there was an agreement in all the views. (Fig. 2)

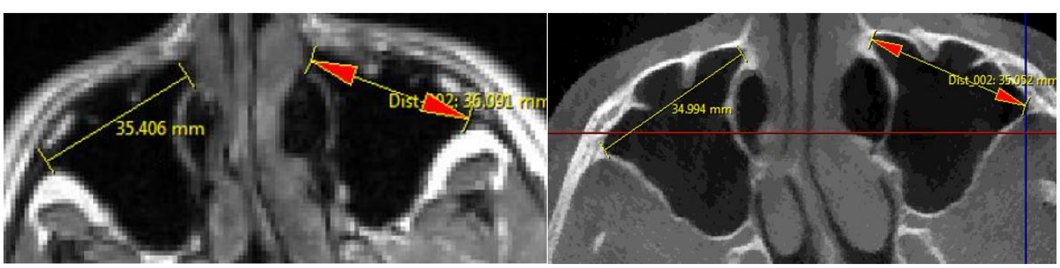

Figure 2. Measurement of the width of the maxillary sinuses. Shown here are right and left maxillary sinuses on CBCT slice (right) and MRI slice (left).

Length was measured as the longest distance between the most anterior point and the most posterior point of the medial wall of the maxillary sinus in the axial view, (AR-PR and AL-PL) after scrolling through all the images and there was an agreement in all the views. (Fig. 3)

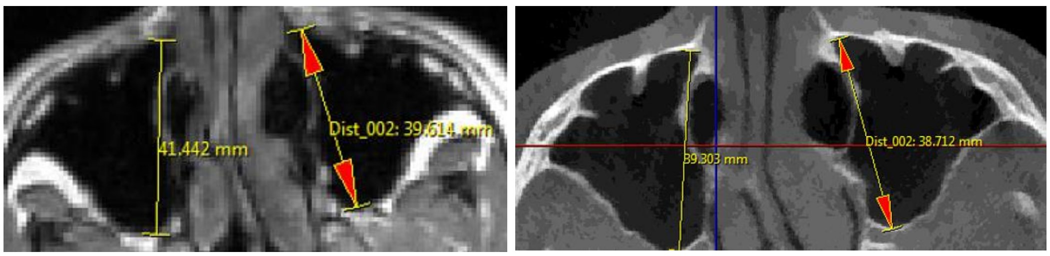

Figure 3. Measurement of the length of the maxillary sinuses. Shown here are right and left maxillary sinuses on CBCT slice (right) and MRI slice (left).

For all measurements of the maxillary sinuses, the CBCT and MRI images were imported as DICOM files into Simpleware, Scan IP: 2018-03 (Exeter, United Kingdom) which allowed for segmentation and calculation of the width, height, length and volumes of a 3D object. Both CBCT and MRI files were opened in DICOM and saved in the software extension as a project. Then the images were registered together so that both images were seen and superimposed using the register background tool. The same five points were chosen on each MRI and CBCT image so that the images were superimposed in identical positions. To increase the accuracy of the measurements, images were registered (superimposed) in three planes. With the CBCT and MRI files open in the axial view, five landmarks were selected: 1) apex of the right maxillary central incisor, 2) apex of the left maxillary central incisor, 3) apex of the left maxillary canine, 4) apex of the right maxillary canine, 5) tip of the odontoid process of the second cervical vertebra.

After the image registration was complete, CBCT and MRI images were measured and segmented separately.

To do the volume segmentations, the threshold tool was used to delineate the exact location of the segmentation. In order to isolate the maxillary sinuses, the paint tool was used to unpaint all structures except for the maxillary sinuses. Once the maxillary sinuses were isolated, the right and left maxillary sinuses were separated into two regions by using the ungroup mask tool. The maxillary sinuses were then isolated in more detail by using the cleaning tool slice by slice. In order to calculate the volume, a 3D model of the sinuses was generated, and the general statistics tool was used to calculate the volume of the right and left maxillary sinus. (Fig. 4)

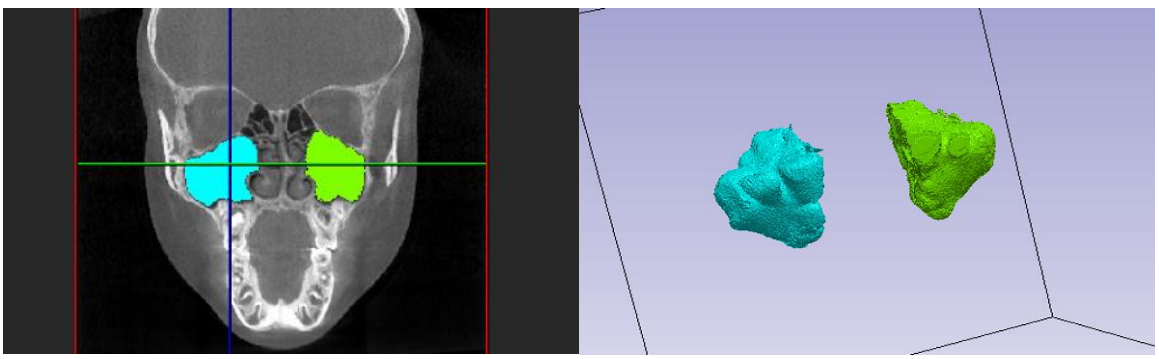

Figure 4. 3D model of sinuses generated in order to calculate sinus volume.

A total of 22 maxillary sinuses were measured. The measurements from MRI and CBTC images were compared using Intraclass Correlation Coefficient (ICC) and by generating Bland-Altman plots. All tests of hypotheses were two-way with $\alpha = 0.05$ using SPSS (Chicago, IL).

Results

The results indicate excellent agreement between CBCT and MRI measurements. Average Intraclass Correlation Coefficient (ICC) between CBCT and MRI were 0.991-0.997. There was no statistically significant systematic bias when comparing CBCT and MRI measurements ($p>0.05$) for all but one measurement. The One Sample Wilcoxon test was performed to determine if the mean difference between the CBCT and MRI measurements was significantly different from zero. Only the volume of the left maxillary sinus was significantly different from zero ($p = 0.016$) indicating the presence of a systematic bias where MRI measurements were consistently larger than CBCT measurements. Kendall's tau correlation was also conducted to determine if the CBCT and MRI modalities do not agree equally through the range of measurements (proportional bias). Proportional bias was only observed for the volume of the left maxillary sinus (tau = -0.624, $p = 0.008$), where the difference between CBCT and MRI measurements consistently was larger when evaluating larger CBCT and MRI measurements (Fig. 5) compared to the rest of the measurements where no statistically significant bias was observed (Fig. 6, 7, 8, 9, 10, 11, 12).

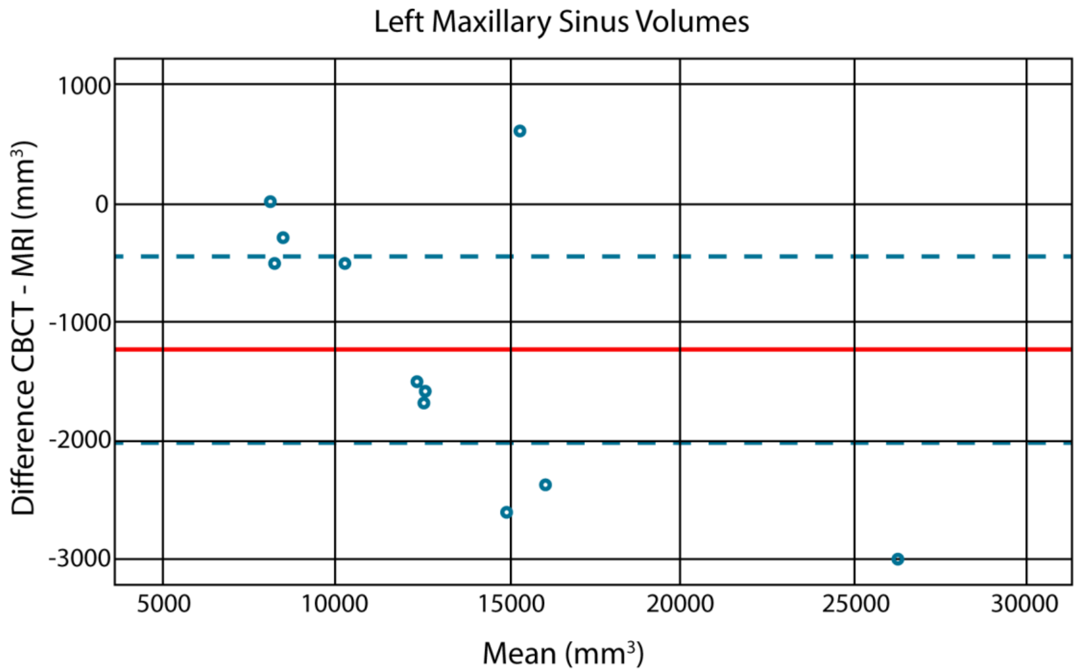

Figure 5. Bland Altman plot indicating the bias present for the volume of the left maxillary sinus (p=0.016).

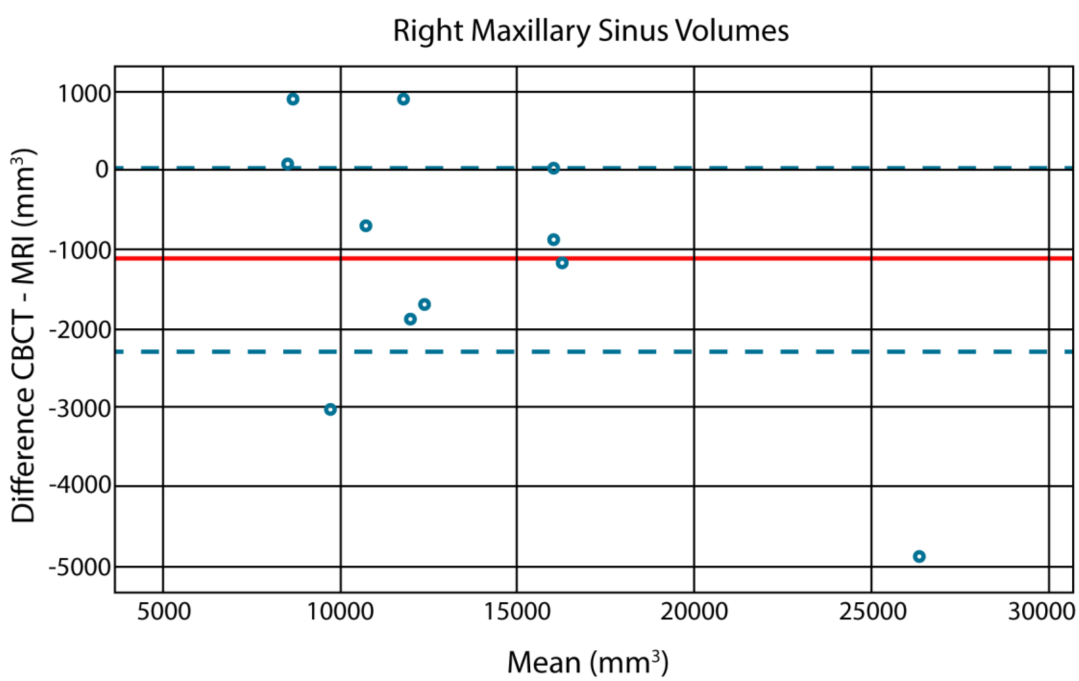

Figure 6. Bland Altman plot for the volume of the right maxillary sinus.

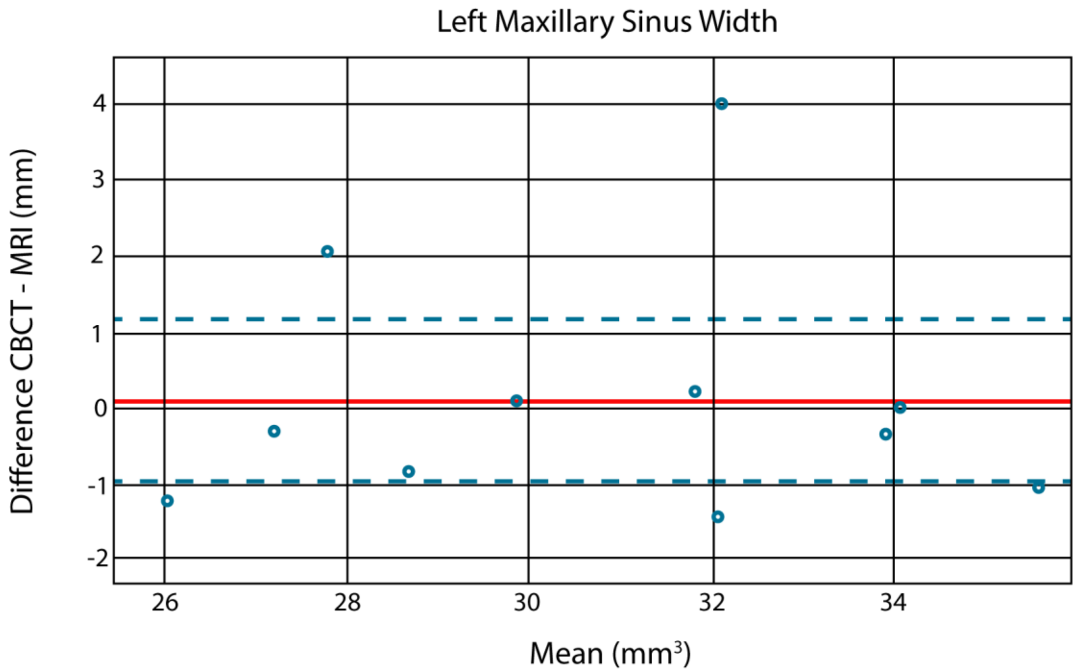

Figure 7. Bland Altman plot for the width of the left maxillary sinus.

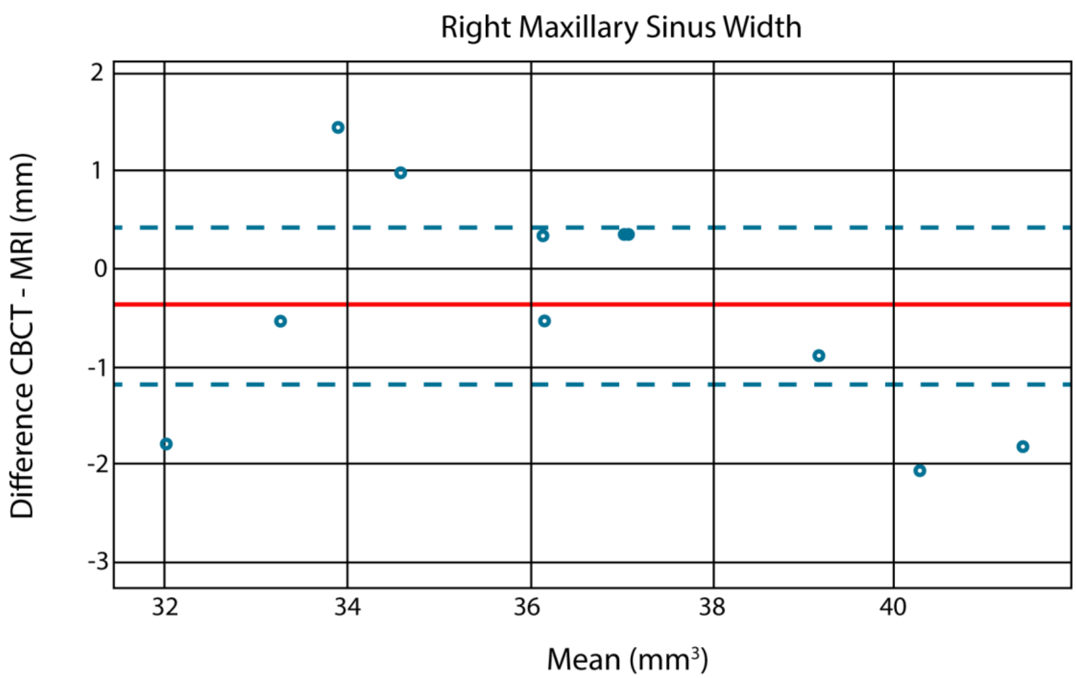

Figure 8. Bland Altman plot for the width of the right maxillary sinus.

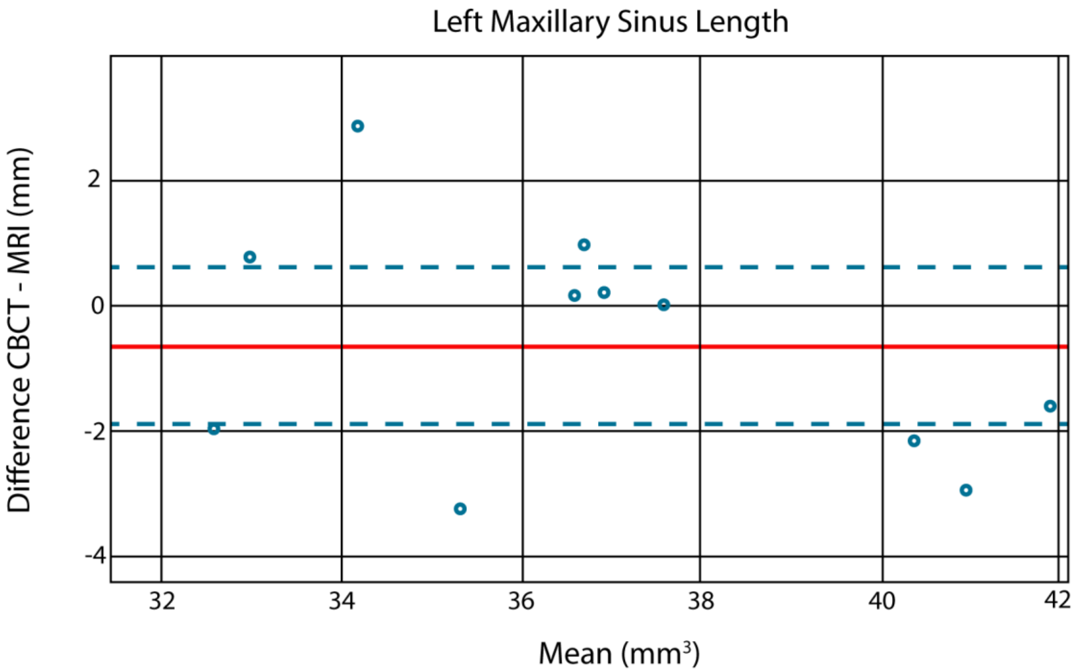

Figure 9. Bland Altman plot for the length of the left maxillary sinus.

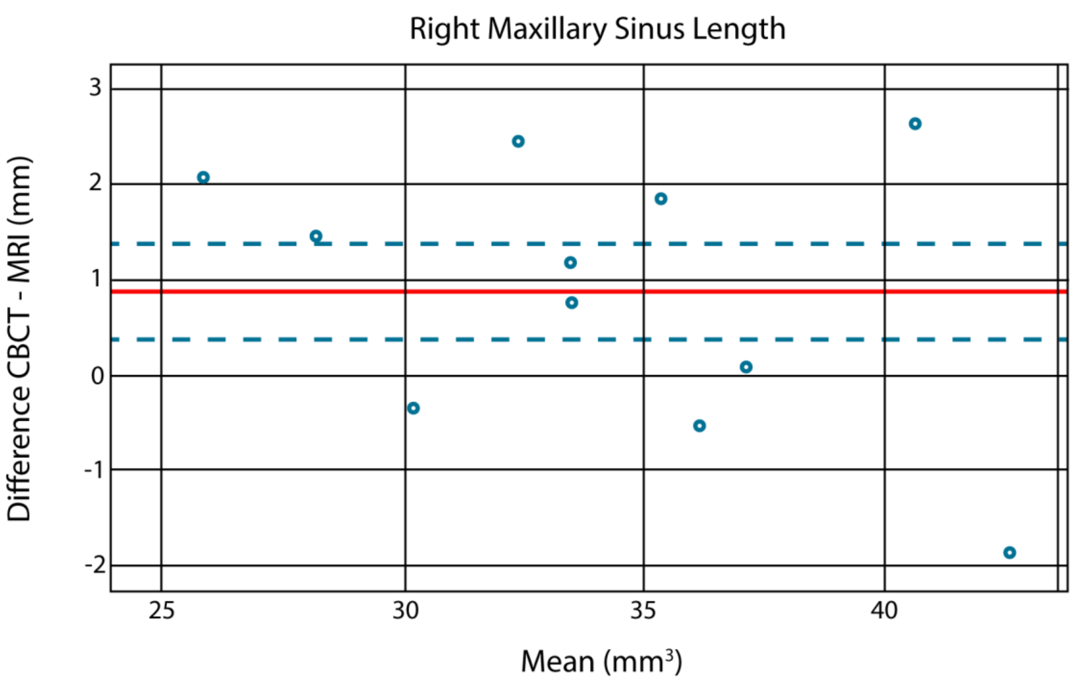

Figure 10. Bland Altman plot for the length of the right maxillary sinus.

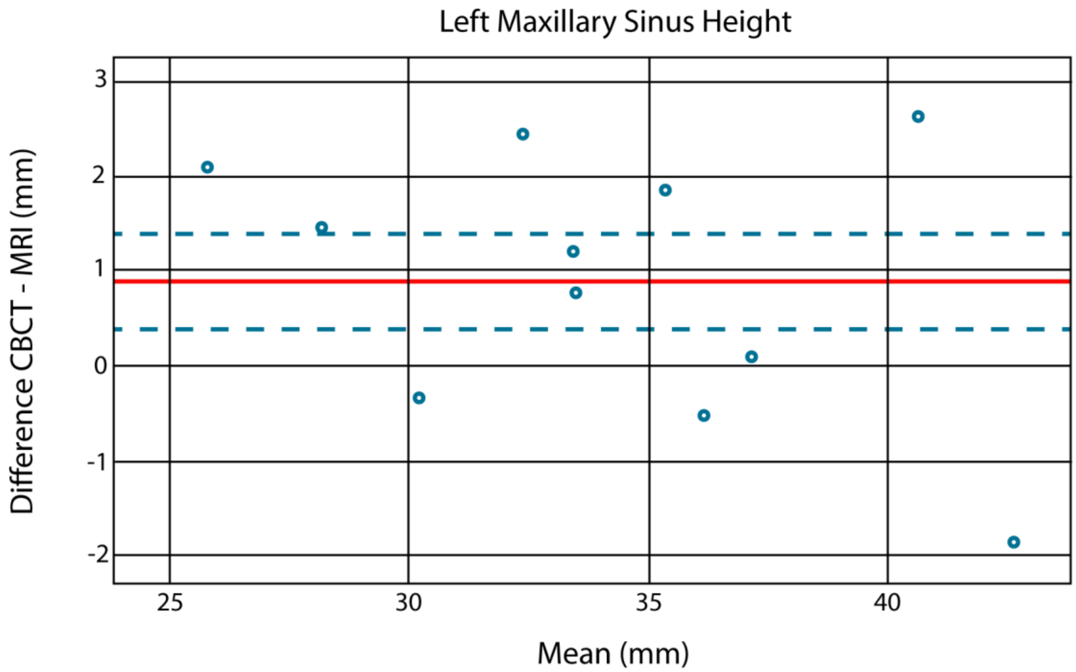

Figure 11. Bland Altman plot for the height of the left maxillary sinus.

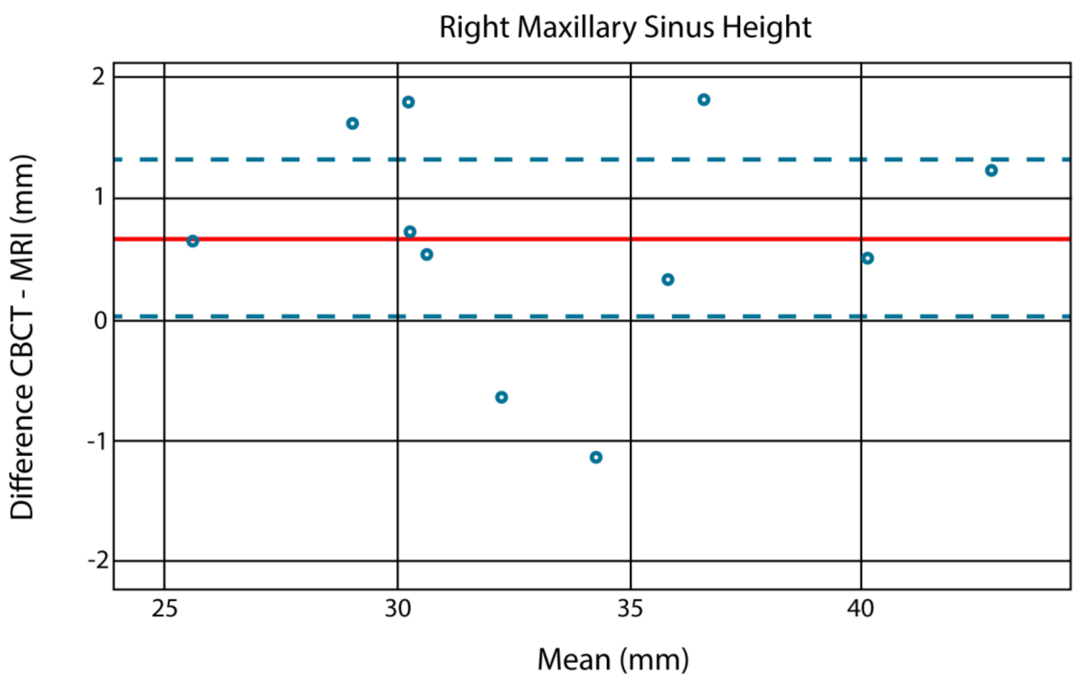

Figure 12. Bland Altman plot for the height of the right maxillary sinus.

Reliability of measurements was tested by re-measuring maxillary sinuses for four subjects on CBCT and MR images at four weeks following the original measurements. Reliability was very high for CBCT and MRI. Mean Intra-observer ICC were 0.999 - 1.000 for CBCT and 0.993-0.998 for MRI.

Discussion

The purpose of this study was to compare the accuracy of maxillary sinus measurements made on CBCT and MR images. Measurements made on MRI showed near perfect agreement with equivalent measurements taken from CBCT images. (ICC 0.991-0.997). Mean Intraobserver ICC was also very high (0.999 -1.000) for CBCT and (0.993-0.998) for MRI. Therefore, the results support the hypothesis tested.

The volume of the left maxillary sinus had statistically larger MRI values than CBCT. However, although not statistically significant, the volume of the right maxillary sinus was also larger for MRI than for CBCT for 7 out of 11 patients. There are several reasons this may have occurred. Firstly, there are some challenges in multimodality image assessment such as different field of views, voxel sizes, voxel values, slice thickness, image resolution, field inhomogeneity, and image artifacts. Both bone and air appear black on MR images, since they do not give an MRI signal. Since the maxillary sinus space is outlined by bone, the delineation between the bone and airspace of the maxillary sinuses in CBCT images was clearer than in MR images. In MR images, since airspace and bone are both radiolucent, when calculating volumes, it was harder to distinguish where the airspace ended and the bony outline began, resulting in larger volumes for the MR images. In addition, acquisition time for each imaging modality is also different, with MRI having an acquisition time of 4 minutes versus CBCT, which has a 5.4 second acquisition time. Since the acquisition time for MRI is longer, a patient will be inhaling and exhaling, and may even be moving slightly during this time, which could affect the image.[11]

One of the biggest differences between MRI and CBCT is that these two imaging techniques focus on different structures. MRI focuses on soft tissues while CBCT focuses on hard tissue. Of the patients who had sinus pathologies, all of them were in the left sinus. The consistently larger MRI volumes for the left sinus may be due to the ability to better distinguish between the bony soft tissue interface of the sinus in the MRI versus the CBCT. In a study done by Khoo et. Al, a comparison of clinical target volumes for base of skull meningiomas also found that MRI volumes were consistently larger than those calculated from CBCT.[27] It was found that in CBCT imaging of soft tissue near bone, the X-rays from the CT were preferentially absorbed by the bone, causing imaging artifacts, which impair the ability to clearly delineate lesions near bony structures. On the other hand, the use of MRI enhances the ability to visualize soft tissue lesions near bone.[27] Since the presence of sinus pathology was more abundant in the left sinus, this may partially explain the statistically significant larger volume left MRI measurements when compared to CBCT measurements. Although volumes calculated from MRI were slightly larger than volumes calculated from CBCT, near perfect agreement suggest that both MRI and CBCT can be used to evaluate the maxillary sinus because the slight difference will not affect clinical judgement.

MRI imaging has the potential to be used for diagnostic purposes in the field of orthodontics, however larger sample sizes are required in order to more accurately assess the potential of MR images as an alternative to CBCT.

Conclusion

1. Maxillary Sinus measurements made on MRI showed near perfect agreement with equivalent measurements taken from CBCT images (ICC 0.991-0.997).
2. Maxillary Sinus volumes measured on MRI are generally higher than maxillary sinus volumes made on CBCT.

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CHAPTER THREE

EXTENDED DISCUSSION

The agreement between measurements made on the maxillary sinuses is very high between MRI and CBCT, however there are still some limitations to using MRI as a diagnostic tool in orthodontics. One major drawback is that MRI has poorer visualization of hard tissues including bone and teeth. Piano and Taylor's studies showed high correlation between tooth length measurements made on CBCT and MRI, however, it was noted that making measurements on MR images was more difficult than on CBCT.[25,26] Enhancing the visualization of the dentition using proton-rich intraoral contrast may increase the accuracy of tooth length measurements made on MR images.

MR images have shown a high agreement with CBCT images in measuring tooth lengths, length of the condylar process and mandibular ramus, and maxillary sinus dimensions. A study by Markic et al., assessed the length of the mandibular ramus and the condylar process and concluded that since CBCT and MRI were nearly equal in their ability to measure the condylar process, MRI is recommended because it avoids ionizing radiation and has higher sensitivity in detecting inflammation.[28] If more studies comparing other craniofacial structures in CBCT and MRI are done and show similar results, this can substantiate the notion that other measurements required for orthodontic diagnosis can be extrapolated from MR images. Using MR imaging instead of CBCT scans for orthodontic diagnosis and treatment planning will relieve vulnerable patients from the harmful effects of ionizing radiation all together.

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APPENDIX A

MAXILLARY SINUS MEASUREMENTS (mm) MADE ON CBCT SCANS.

	PT #1	PT #2	PT #3	PT #4	PT #5	PT #6	PT #7	PT #8	PT #9	PT #10	PT #11
HEIGHT RIGHT	43.475	33.750	30.622	36.021	25.914	30.903	37.531	31.952	29.851	31.110	40.434
HEIGHT LEFT	41.679	36.242	30.014	37.190	26.842	33.584	35.870	33.870	28.892	34.033	41.907
WIDTH RIGHT	33.801	34.242	26.745	32.253	27.240	27.618	36.789	26.906	29.740	31.796	34.994
WIDTH LEFT	33.740	31.335	25.434	34.112	27.058	29.913	34.041	28.832	28.258	31.910	35.052
LENGTH RIGHT	39.483	37.611	33.706	33.364	35.619	37.014	41.116	36.688	31.605	37.191	39.303
LENGTH LEFT	40.492	37.236	35.893	31.110	34.615	36.318	39.263	35.073	32.986	37.273	38.712

APPENDIX B

MAXILLARY SINUS VOLUMES (mm^3) MADE ON CBCT SCANS.

	PT #1	PT #2	PT #3	PT #4	PT #5	PT #6	PT #7	PT #8	PT #9	PT #10	PT #11
VOLUME RIGHT	23,900	11,000	8,230	15,600	8,480	9,130	16,000	11,500	10,300	12,200	15,700
VOLUME LEFT	24,800	11,700	8,320	13,700	7,900	8,140	15,600	11,700	9,970	11,500	14,800

APPENDIX C

MAXILLARY SINUS MEASUREMENTS (mm) MADE ON MRI SCANS.

	PT #1	PT #2	PT #3	PT #4	PT #5	PT #6	PT #7	PT #8	PT #9	PT #10	PT #11
HEIGHT RIGHT	42.240	34.898	29.905	35.697	25.273	30.371	35.707	32.595	28.240	29.315	39.933
HEIGHT LEFT	43.537	34.392	30.352	37.101	24.767	31.143	36.398	33.099	27.451	32.851	39.283
WIDTH RIGHT	34.494	34.061	25.421	34.058	27.501	28.360	36.789	27.649	30.352	31.383	35.406
WIDTH LEFT	34.086	32.779	26.662	30.123	27.392	29.815	34.041	26.798	29.091	31.695	36.091
LENGTH RIGHT	42.411	37.591	36.959	32.602	32.755	36.805	42.714	36.509	33.557	36.218	41.442
LENGTH LEFT	42.337	36.885	36.424	32.911	33.166	35.976	41.317	34.090	33.536	36.913	39.614

APPENDIX D

MAXILLARY SINUS VOLUMES (mm^3) MADE ON MRI SCANS.

	PT #1	PT #2	PT #3	PT #4	PT #5	PT #6	PT #7	PT #8	PT #9	PT #10	PT #11
VOLUME RIGHT	28,800	12,900	11,300	16,500	8,420	8,210	16,000	13,200	11,000	11,300	16,900
VOLUME LEFT	27,800	13,300	8,590	16,300	8,430	8,110	15,000	13,400	10,500	13,000	17,200

1