CBCT Measurements of Maxillary Molars and Relation to the Buccal/Palatal Plate and Sinus

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Dedication

To my precious family, for always supporting my efforts to grow in my educational pursuits.

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Abstract

Objective: Surgical manipulation of human tissues during endodontic surgery requires that the clinician be knowledgeable of anatomic dimensions. If a CBCT is not available due to location/cost, it is prudent for the clinician to consult a knowledge base for the surgical site. Knowledge of the buccolingual (BL) and mesiodistal(MD) thickness on maxillary molar roots at the preferred level for root resection(3mm), the distance between the root apices of the 1^{st} and 2^{nd} molars, and he proximity of each root apex to the maxillary sinus will help the surgeon before and during the surgical procedure.

Methods: Cone beam computed tomography scans from 155 patients were used to evaluate measurements from 505 teeth and respective areas

Results: 1) Buccal bone was thinnest over the MB root of the 1^{st} molar (0.84mm) and thickest over the MB root of the 2^{nd} molar (1.91mm). **2)** The thickest root (B-L dimension) was the MB root of the 1^{st} molar (5.49mm), and the thinnest was the palatal of second molar (3.81mm). The largest root (M-D dimension) was the palatal root of the 1st molar (4.3 mm), and the smallest was the DB root of the 2nd molar (2.87mm). **3)** The MB and DB roots of the 2nd molar were the closest in proximity of roots (1.00mm). **4)** The MB root of the 2nd molar has the closest proximity to the sinus floor with an average distance of 0.66mm.

Conclusion: Understanding of the maxillary posterior tooth anatomy for apical resection is beneficial to the endodontist. The root width and its relative position to the sinus can aid the surgeon in performing the root resection.

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Introduction

Preservation of the dentition and maintenance of function are the dental profession's ultimate goals. More patients expect and demand that their teeth be saved and not extracted, which is reflected in the increase in endodontic treatments. The introduction of new instruments and devices to improve nonsurgical endodontic treatment has been explosive in the past decade. The trained practitioner should consider surgical endodontic therapy when more conservative treatments have not achieved complete healing, are contraindicated, or stand little chance of removing the etiology. Surgery should be considered a continuum of planned endodontic therapy. Therefore, it should be coordinated with nonsurgical modalities to appropriately bring about favorable outcomes. The knowledgeable clinician will remember that the goals of endodontic therapy are still the same: complete cleaning and shaping, disinfection/sterilization and 3-D obturation.[1]
Endodontic surgery has now evolved into endodontic microsurgery. By using state-of-the-art equipment, instruments and materials that match biological concepts with clinical practice, we believe that microsurgical approaches produce predictable outcomes in the healing of lesions of endodontic origin. [2]

Before surgery, it is imperative for the clinician to be familiar with the anatomical landmarks and structures adjacent to surgical, as well as tooth dimensions and anatomy. The buccal and lingual bone thickness, the dimensions and inclination of roots, and the adjacent anatomical structures, especially nerve and sinus location, are all critical factors in planning and performing the osteotomy and the root-end resection/root-end filling procedure.

Several specific changes in the microsurgical approach are proven to increase the procedure's success. Some of these changes include a smaller osteotomy (approximately 3-4mm in diameter), root-tip resection length of 3 mm to eliminate lateral canals and apical ramifications, and a decreased or flat root resection bevel angle. Clear inspection of the resected root surfaces is needed to visualize fractures, isthmuses or other anatomical complexities .[3]

Radiographic information is often used to help manage endodontic problems, from diagnosis and treatment to assessing outcome. Cone beam computed tomography as one of the diagnostic tools that can help the practitioner obtain more accurate measurements for diagnosis and treatment planning.

CBCT allows for accurate 3D reconstruction of the dentofacial structures. In comparison periapical and panoramic films can distort (3.4%) and magnify (14%) structures.[4]

Review of literature

Morphology

In 1925 when Hess and Zurcher[5] first published their study, it became clear that teeth had complicated root canal systems rather than the simplified canals which had previously been described (Carrotte, 2004) [6]. The ultimate objective of endodontic therapy is to restore and maintain normal apical tissue health. To achieve this objective, infected tissue and bacteria must be thoroughly removed from these complicated canal systems.

Several causes of non-healing endodontic lesions have been identified, including but not limited to 1- inadequate cleaning and shaping due to failure to recognize and locate a portion of a canal system most commonly the apical 3 mm named critical zone by Sequeira et al (2004)[7] 2- persistent bacteria like Actinomycosis [8]3- presence of bacteria outside the canal [9,10]

Therefore, it is imperative for the endodontist to be thoroughly familiar with root canal anatomy, in order to clean, shape, and obturate the root canal system for optimal healing. We also need to keep in mind that with cases of a non-healing lesion of endodontic origin, performing the endodontic microsurgery is often inevitable. The complicated anatomy of the pulp canal system explained below is often why the root end resection/root end filling (RER/REF) is a necessary addition to endodontic treatment procedures.

For each tooth in the permanent dentition, there is a wide range of variation reported in the literature for the number and the shape of canals in each root, the number of roots, and the incidence of molar root fusion. A number of factors contribute to the variation found in these studies, such as: ethnicity, background, age and gender of the patient, source of studied teeth (specialty endodontic practice vs. general practice), study design (*in vitro* vs. *in vivo* studies), methods implemented to find canals (radiography, SEM, decalcification, sectioning, CBCT, micro CT, ink studies, and the use of Dental Operating Microscope and ultrasonics).[11]

In 1958 Green, sectioned the root canals of 110 extracted human molars at two levels: ½ to 1 mm, and 5 to 6 mm from the apical foramen. Mean cross-sectional diameters of 300 root canals were calculated. At 1 mm from the apex, the range in small canals (M of mandibular molars and MB and DB of maxillary molars) was ~ 200 to 400 microns. In large canals (D of mandibular molars and P of maxillary molars), the range was ~400 to 700 microns.[12]

In 1975, DeDeus inspected 1140 extracted teeth under microscope after dye, vacuum, and decalcification to determine the frequency, location, and direction of lateral, secondary, and accessory canals in human teeth. The premolars and molars showed the greatest variety of ramifications. Of these teeth, 17% had ramifications in the apical area, 8.8% in the body of the root, and 1.6% in the base of the root. These ramifications are very important for the clinician, since they communicate with the Periodontal ligament.

Knowledge of the frequency, location and direction of the lateral, secondary and accessory canals will aid the clinician in determining their role in endodontic diagnosis, treatment, and prognosis.[13]

Degerness and Bowles examined the mesiobuccal roots of 153 first and second maxillary molars at 8X with a stereomicroscope after being embedded and sectioned at 1 mm thickness. The number of canals observed in maxillary first and second molars was 20% and 38.1% for one canal, 79.8% and 60.3% for two canals, and 1.1% and 1.3% for three canals, respectively. The average distance between the two main canals was 1.2 ± 0.6mm in first molars and 1.78 ± 0.6mm in second molars. Isthmus tissue increased greatly at 3.6 mm from the apex, suggesting optimal root resection at this level.[14]

In Stropko's clinical study on canal morphology of maxillary first and second Molars, MB2 was found in 73.2% of 1st molars, 50.7% of 2nd molars, and 20% of 3rd molars. He also reported that the MB2 canal is a separate (Type III) canal in 55% and 46% of 1st and 2nd molars respectively. The operating microscope and troughing techniques are crucial to finding MB2 canal.[15]

In a study by Versiani al on 4 rooted maxillary second molars the size of the roots was similar, and most of them presented straight with 1 canal, except the mesiobuccal that showed 2 canals in 24% of the samples. The configuration of the pulp chamber was mostly irregular quadrilateral-shaped and there were no furcation canals. Accessory canals were located mostly in the apical third of the roots, and apical delta was observed in 12% of the roots.[16]

According to Allen et al, the most frequently missed canals were in Mx 1st molars. Canals were missed more often during treatment of older patients which might help explain why there is a greater level of endodontic surgery performed in patients > 40 yr of age[17].

Hoen and Pink also reported the most commonly treated tooth to be maxillary first molar. Missed canals were located in 42% of the teeth. 89% of the teeth with asymmetric obturations (>0.5mm) had an untreated canal[18.]

Jin et al studied a Chinese population using CT images of 66 patients. 33 males and 33 Females between the ages of 14 to 80 years old. The images were created by taking a series of 1 mm-thick cross-sectional slice images under a high-resolution bone algorithm, with a 9.6 cm diameter field of view. Measurements were done in axial view, which is similar to the measurements were performed in the current study.

Thickness of the buccal bone over the mesio-buccal and disto-buccal roots of the second molar was thicker than the first molar which were 1.91 mm and 1.52 mm. They also found the average thickness for palatal bone over the first molar at the level of the apex to be 3.15 mm and this thickness for second molar to be 3.08 mm. In regard to differences between males and females , Jin et al also reported that, most of the maxillary and mandibular teeth showed thicker bone plates in men than in women, but this disparity was not found to be statistically significant.[19]

Anatomy of maxillary sinus in relation to apices of maxillary molars

The maxillary sinus is the first of the paranasal sinuses to develop in fetal life. It is typically pyramidal in shape, with the base forming the lateral nasal wall and the apex extending into the zygoma. The floor of the sinus is formed by the alveolar process of the maxilla. In about 50% of the population, the sinus expands into the alveolar process, placing it in close relation to the roots of the premolars and molars. Imaging of part or the entire sinus can be accomplished with standard dental radiographs, the Water's view, CT, and MRI. During surgery of maxillary posterior teeth, the sinus is at risk for exposure as a result of surgical procedures or by pathologic invasion. Perforation into the sinus does not often result in permanent dysfunction. The mucosal membrane has been shown to regenerate within 5 months. Bony healing will usually occur provided primary closure of the surgical wound occurs. Antibiotics, analgesics and decongestants are indicated for the treatment of sinus perforations, with clinical improvement with 48-72 hrs.[20]

In a study by Aghacayak et al on maxillary sinuses, they found that the volume of maxillary sinus in oral breathers (>5 years) was significantly lower than in nasal breathers, but it remains unclear whether this is due to malfunctioning of the nasal cavity or due to the underlying pathological condition.[21]

Eberhardt et al in 1992 used CT images *in vivo* and *in vitro* to determine the distances between the apices of maxillary posterior teeth to floor of the maxillary sinuses, and the thickness of the lateral bone covering these apices. There was NSD between *in vivo* and *in vitro* findings in their study. They reported that the apex of the MB root of maxillary 2nd molar was closest to the sinus floor (mean 1.97 mm) but farthest from the buccal bony surface (mean 4.45 mm). The apex of the buccal root of the Mx 1st premolar was closest to the buccal bony surface (mean 1.63) but farthest from the floor of the sinus (7.05 mm). Based on the thickness of bone, one could reason that the palatal roots of 1st and 2nd molars should be approached palatally whereas the palatal root of 1st premolars should be approached bucally. [22]

Ok et al did a study in Turkish population to evaluate the relationship between each root of maxillary premolars and molars and the maxillary sinus floor according to sex, sinus position, and age by decade They looked at scans from 849 patients and they also created a classification for the relationship between root apices and the sinus floor such as type I ,II and III. Type I were the roots that were penetrating the sinus, type II were the roots that contacted the sinus floor and in type III roots extended below the sinus floor. Type 1 occurred mostly in palatal root of first molar, Type 3 in MB and DB of first molar and type 2 in MB of second molars. They found the maxillary first premolars to have no relationship with the maxillary sinus floor, but the maxillary second molars are closer to the sinus floor. Also, the second decade and males were most susceptible to undesirable results, as there is an increased rate of root penetrating the sinus.[23] Some undesirable results include inadvertent extrusion of dental materials such as debris, NaOCl irrigant, sealer, calcium hydroxide, or even filling material (which may lead to maxillary sinus aspergilliosis).[24]

Kilic et al assessed the relationship between the maxillary sinus floor and the maxillary posterior teeth root tips using dental cone-beam CT. A total of 87 right and 89 left maxillary sinus regions from 92 patients were examined using dental cone-beam CT by a specialist in oral and maxillofacial radiology. Images were grouped according to the relation between the root tips and the maxillary sinus floor, as follows: Group 1: Root tips in contact with the sinus floor; Group II: Root tips penetrating into the sinus, and Group 3: Root tips below the sinus floor .

Distances were measured for each side of each tooth and root tip. Root tips in Group 1 were numbered as zero, those in Group 2 were given negative numbers and those in Group 3 were given positive numbers. The distance between sinus floor and root tip was longest for the first premolar root tip and shortest for the second molar distobuccal root tip for both right and left sides. No statistically significant differences were found between the measurements for right and left sides or between female and male patients. For the right side 60% of the root tips were included in group 3, 30% in group 1 and 10% in group 2 whereas on the left side 68% were included in group 3, 21% in group 1 and 11% in group 2.[25]

Sinus complications during endodontics microsurgery

Watzeck and Bernhart described maxillary sinus anatomy, vasculature, innervation, tooth morphology, sinus physiology, diagnosis and sinus evaluation, and treatment of symptoms and sinusitis. According to their review, sinus perforation occurred in 28% of maxillary endodontic surgeries. The perforation and the size of the periapical inflammation had no influence on the treatment outcome. There was No statistical significance in the healing rate between those with and without sinus exposure. a radiographic check prior to surgical closure may help ensure that no foreign bodies are left in the sinus.[26]

Freedman et al addressed the maxillary sinus perforation associated with apicoectomy in maxillary posterior teeth. A review of 472 such procedures showed an occurrence rate of 10.4% (23% in molars, 13% in 2nd premolars, and 2% in 1st premolars). This low incidence, coupled with no recorded cases of sinusitis, favors this treatment before extraction but demands meticulous surgical technique and appropriate postoperative care.[27]

Maxillary sinusitis and possible dental etiology

Maxillary sinusitis may or may not be dental in origin. If dental in origin (approximately 10%), it may be the result of periapical infection, periodontal disease or perforation during surgery. [26]Non-dental sources of origin include upper respiratory infection, allergies, and chemical irritation.

Radiographic images to view the maxillary sinus include Water's projection, panoramic, occlusal, lateral head, and maxillary molar periapical radiographs. If one of the sinuses is diseased, the image may show a radiopaque fluid level, sinus opacification, mucosal hyperplasia, a radiopaque growth, or a loss of cortical borders of the sinus. Pathologies that may involve the maxillary sinus include mucous retention cyst, foreign objects, oro-antral fistula, odontogenic and non-odontogenic cysts, metabolic diseases and neoplasms.[26]

Maillet et al described the radiographic characteristics of odontogenic maxillary sinusitis as seen on cone-beam computed tomography (CBCT) scans and determined whether any tooth or root was more frequently associated with this disease.

Changes in the maxillary sinuses appear associated with periapical pathology in greater than 50% of the cases. Maxillary first or second molar teeth are most often involved, and individual or multiple roots may be implicated in the sinusitis.[29]

CBCT and diagnosis in dentistry

In 1895, Wilhelm Konrad Roentgen discovered x-rays could darken a photographic plate. He named this discovery “x-ray” after the algebraic symbol for an unknown quantity.

In 1896, six weeks after Roentgen discovered x-rays, Otto Walkoff made the first dental radiograph of his own teeth, which required 25 minutes of exposure time. Processing the film took one hour. In 1899, Radiology was first introduced into endodontics when Dr. Edmund Kells inserted a lead wire into a maxillary incisor to determine it’s length Goldman et al mentioned that radiographic interpretation is a subjective process.

When shown the same radiographs 6 months apart, examiners agreed with themselves 75 to 83% of time, but when comparing various categories large discrepancies were observed.[30]

CBCT is a technology that produces three-dimensional (3D) digital imaging at reduced cost and less radiation for the patient than traditional CT scans.

It also delivers faster and easier image acquisition. By providing a 3D representation of the maxillofacial tissues in a cost- and dose-efficient manner, a better preoperative assessment can be obtained for diagnosis and treatment. [31]

In medical (Fan-beam) CT the number of slices refers to the amount of time the radiation source rotates around the patients head. (4-,8-,12-,16-,32-, and 64-slice machines) Images acquired using a linear array of solid-state detectors, and a small gap exists between each parallel slice. The accumulated “gaps” between slices contribute to a built-in-error.[32]

In cone-beam CT, the scanner rotates once around patients head (360°) then images are acquired by taking cone-shaped volume and algorithmically producing a dimensionally gapless image.[33] Xray beam limitation, image accuracy, rapid scan time, dose reduction and chairside display mode are all advantages of CBCT over conventional CT.[34]According to Estrela et al periapical radiography was 54.5% as accurate and panoramicradiography was 27.8% as accurate at determining apical periodontitis as that diagnosed from CBCT images. [35]

CBCT showed significantly more lesions (34%) than PA radiography, with greater accuracy in second molars and roots with close proximity to the maxillary sinus floor. Periapical radiography offered limited lesion detection for teeth with apices in close contact to the maxillary sinus floor, for molars (especially 2nd molars) and when bone thickness between lesion and sinus was $\leq$ 1 mm. [36]

Bornstein et al showed that of 58 lesions detected with sagittal CBCT sections, 15 (25.9%) were not detected with PA radiography. PA radiographs underestimate the real extent of lesions in comparison to CBCT. When performing apical surgery in mandibular molars, one has to expect a cortical bone wall with a mean thickness of 1.7 mm and a mean access distance of 5.3 mm.[37]

American Dental Association Council on Scientific Affairs promotes safe use of (CBCT) and appropriate professional justification Of CBCT imaging procedure.

The CSA reviewed the current research literature to develop collaborative guidance regarding the use of CBCT in dentistry with input from a broad group of stakeholder organizations. The Council's principles for CBCT safety may be applied to any number of potential dental CBCT imaging applications.[38]

PRACTICE IMPLICATIONS:

As with other radiographic modalities, CBCT imaging should be used only after a review of the patient's health and imaging history and the completion of a thorough clinical examination. Dental practitioners should prescribe CBCT imaging only when they expect that the diagnostic yield will benefit patient care, enhance patient safety or improve clinical outcomes significantly[39].

The 2007 recommendations of the International Commission of Radiological Protection (CRP), which include salivary glands, extrathoracic region, and oral mucosa in the calculation of effective dose, result in an upward reassessment of fatal cancer risk from oral and maxillofacial radiographic examinations[40].

Dental CBCT can be recommended as a dose-sparing technique in comparison with alternative medical CT scans for common oral and maxillofacial radiographic imaging tasks.

CBCT dose varies substantially depending on the device, Field of view and selected technique factors. Effective dose detriment is several to many times higher than conventional panoramic imaging and an order of magnitude or more less than reported doses for conventional CT.[41]

Effective dose (E_{2007}) from a standard dental protocol scan with the medical CT was from 1.5 to 12.3 times greater than comparable medium-field of view dental CBCT scans.[38]
Below is the summary of Joint Position Statement of the American Association of Endodontists and the American Academy of Oral and Maxillofacial Radiology:
All radiographic examinations must be justified on an individual needs basis whereby the benefits to the patient of each exposure must outweigh the risks. In no case may the exposure of patients to X-rays be considered "routine," and certainly CBCT examinations should not be done without initially obtaining a thorough medical history and clinical examination. CBCT should be considered an adjunct to two-dimensional imaging in dentistry. Limited field of view CBCT systems can provide images of several teeth from approximately the same radiation dose as two periapical radiographs, and they may provide a dose savings over multiple traditional images in complex cases.[42]
In a study by Vizzoto et al CBCT was associated with higher mean values of specificity and sensibility than radiographic examination for the detection of MB2 canals. When endodontic retreatment is necessary removal of the root filling prior to the CBCT examination eliminates artifacts, thereby permitting the use of the 0.3-mm voxel protocol

that has good diagnostic performance and lower radiation dose.[43]

Low et al compared periapical (PA) radiography and limited cone-beam tomography (CBT) for preoperative diagnosis in posterior maxillary teeth of consecutive patients referred for periapical surgery. An oral radiologist and an endodontist analyzed images containing 156 roots (37 premolars, 37 molars) were analyzed. CBCT showed significantly more lesions (34%) than PA radiography, with greater accuracy in second molars and roots with close proximity to the maxillary sinus floor.[44] According to Patel et al CBCT overcomes most of the limitations of intra-oral radiography.

Increased diagnostic data with CBCT should result in more accurate diagnosis and monitoring and therefore improve decision making for the management of complex endodontic problems.[45]

When indicated, CBCT may supplement conventional two-dimensional radiographic techniques, harnessing the benefits of each system. The same paper also showed diagnosis using CBCT revealed a lower healed and healing rate for primary root canal treatment when compared to periapical radiographs, particularly in roots of molars. There was a 14 fold increase in failure rate when teeth with no pre-operative periapical radiolucencies were assessed with CBCT compared with periapical radiographs at 1 year.[46]

CBCT and Maxillary Sinus

Maxillary sinuses are covered by a 1 mm thick mucous membrane which may increase 10-15 fold in size when the membrane becomes inflamed. The common causes of odontogenic sinusitis are dental abscesses and periodontal disease. Computed tomography (CT) is considered the gold standard for sinus diagnosis. Recently, cone beam computed tomography (CBCT) has been introduced for dental and maxillofacial imaging, which has several advantages over traditional CT, including lower radiation dose and chair side process. Sheikhi et al looked at the association between mucosal thickening (MT) of the sinus and periodontal bone loss (PBL) and pulpoperiapical condition. MT was observed in 39.4% of patients (mean = 4.68 ± 5.25 mm). PBL was seen in 33% of the patients (mean = 1.87 ± 1.63 mm). Linear regression test showed that there is an association between both PBL and pulpoperiapical condition and MT, but the effect of PBL was about 4 times stronger. This study showed that MT of the maxillary sinus was associated with PBL.[47]

In a study by Raghav et al, the authors recorded the prevalence of incidental maxillary pathologies in patients presenting with dental problems using the cone-beam computed tomography (CBCT) scans that were performed for maxillofacial diagnostic purposes. Incidental maxillary sinus abnormalities were highly prevalent in asymptomatic dental patients; hence oral radiologists should be aware of these incidental findings and comprehensively evaluate the entire captured CBCT volume, which can help in early diagnosis, treatment and follow-up ror the patient.[48]

According to Warhekar et al, CBCT referrals by institutions were mostly for implant placement or following trauma whereas private practitioners used CBCT mainly for implant placement followed evaluating impaction. CBCT was being utilized more by oral surgeons in private sector whereas in an Institutional setup, the majority of referrals were from Oral Diagnosis and Radiology departments. Findings that were most commonly diagnosed incidentally on CBCT were orofacial malignancies followed maxillary sinus pathologies.[49]

Santos and Pinhero tested the applicability of cone beam computed tomography (CBCT) to evaluate the integrity of the cortical sinus close to periapical lesions. CBCT proved capable of evaluating the integrity of the cortical sinus (absence of oroantral communication);(OAC) when it lies close to an apical periodontitis lesion. However, the low interobserver agreement reflects the difficulty in performing diagnoses when OAC is adjacent to a periapical lesion, using the acquisition protocol adopted in this research. This could be attributed to the high level of image noise.[50]

Endodontics microsurgery

Preservation of the dentition and maintenance of function are the dental profession's ultimate goals. More patients expect and demand that their teeth be saved and not extracted, which is reflected in the increase in endodontic treatments. The early 1900s saw development of surgical concepts, but the 1910 Focal Infection theory ignited a firestorm of extractions. Endodontics was designated as a specialty in 1964, and since that time, new techniques and a greater foundation of literature have developed. New advances in endodontics such as ultrasonics, the dental operating microscope (DOM), and new root end filling materials led to a focus on microsurgical techniques in the 1990s.[51]

Historically, a surgical approach was often indicated over a retreatment. With the advent of the DOM, nonsurgical retreatment has become much more predictable and the indications for surgery have diminished. The indications today are 1) Failure of nonsurgical re-treatment 2)Failure of initial treatment when re-treatment is not possible or practical or 3)when a biopsy is necessary.[52]

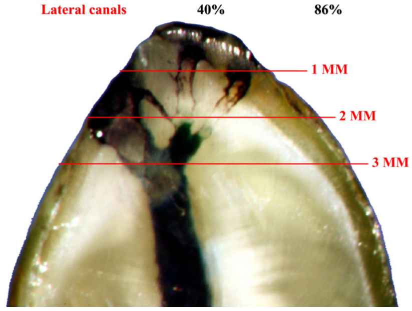
The trained practitioner should consider surgical endodontic therapy when more conservative treatments have not achieved complete healing, are contraindicated, or stand little chance of removing the etiology. Endodontic microsurgery combines magnification and illumination provided by the surgical operation microscope and new microinstruments. Advantages over traditional surgery include: smaller osteotomies, shallow resection angles, and easier identification of the root apex and canal.[47]

Some of the indications may include: anatomical deviations such as tortuous root or a blunderbuss apex, procedural errors such as a ledged canal, and exploratory surgery. Contraindications may include anatomical factors such as proximity to neurovascular bundles and the second mandibular molar area, periodontal considerations (ie. a short root with a deep pocket), and medical factors such as uncontrolled diabetes. The surgeon's skill level and knowledge base may be a contraindication to surgery.[52]

A survey by Creasy et al found that approximately 91% of active AAE members were performing endodontic surgery with 90% using the microscope and ultrasonics. One third of respondents felt their surgical residency training was lacking and 6% of respondents were placing implants. [53]

According to Gutmann and Harrison, some of the indications and rational for root end resection are removal of pathologic processes of teeth, anatomic variations, operator errors in nonsurgical treatment, or the removal of pathosis. It can also help provide access to the canal system and evaluation of the apical seal. A 0 –10˚ bevel with 3 mm resection with evaluation for additional canals have been recommended.[51] A 1 mm resection reduces 52% of the apical ramifications and 40% of the lateral canals, a 2mm resection reduces these by 78% and 86%, respectively, while a 3 mm resection eliminates 93% of apical ramifications and 98% of the lateral canals.[54]

	1 millimeter	2 millimeters	3 millimeters
Apical Ramifications	52%	78%	98%
Lateral canals	40%	86%	93%



In another study by Degerness and Bowles, they mentioned that MB roots should be resected at least 3.6mm from the apex to provide access to the isthmus area between canals. 80% of the accessory canals were located within the apical 3.6mm of the root.[51] The multi-purpose bur produced the smoothest and most uniplanar resected root-end surface with the least root shattering. For refinement, the multifluted carbide finishing bur produced a smoother surface than the ultrafine diamond bur.[55]

According to Weller et al, 40% of the MB roots of the maxillary first molar had 1 canal and 60% had 2 canals. In teeth with 2 canals, the 4 mm sections had a complete or partial isthmus 100% of the time. The incidence of an isthmus was higher in the apical 3-5mm levels[56]

Ultrasonics are able to enlarge/shape the canal for REF with ease and safety as well as maintain parallelism and consistency throughout the depth and width of the preparation. The tips should be sharp. A continuous irrigant is necessary in order to cleanse the area of debris and reduce frictional heat buildup on the root surface. Ultrasonic tips allow cleaner and deeper root end preparations, which could contribute to a higher success rate in surgical therapy, compared to preparations with conventional handpieces.[57]

Abedi et al reported a significantly higher incidence of crack formation in root-end cavities prepared by ultrasonic tips compared with those made by the bur[58], but Layton et al showed significantly more cracks per root when the ultrasonic tip was used on the high-frequency setting for root-end preparation than when the ultrasonic tip was used on the low power setting.[59]

Molars and premolars have the highest rate of persistent disease in endodontic surgery. Though many factors may be identified as the cause for these lower outcomes, the work of Cambruzzi and Marshall in 1983 and of Weller in 1995 defined the relevance of the canal isthmus. An isthmus is defined as a narrow strip of land connecting two larger areas of land, or a narrow anatomic part or passage connecting two larger structures or cavities.[60]

An isthmus can occur in any root in which two or more canals dwell. Studies show that the presence of an isthmus increases and the distance coronal to the apex increases. Modern surgical procedures have provided the best method of identifying and cleaning the isthmus of root during surgery, specifically the DOM and ultrasonic instrumentation.[60]

After root end preparation an ideal root end filling material will improve the success of our endodontic microsurgery. Some of the preferred qualities of ideal root end filling material are 1) being well tolerated by periapical tissues, 2) bacteriocidal or bacteriostatic. 3) Being dimensionally stable and 4) readily available and easy to handle. Some of the more common root end filling materials today are: Endosequence root end repair material which is a new bioceramic material, MTA, Super EBA and IRM
In a dog study by Torabinejad et al, there was less periradicular inflammation with MTA vs. amalgam as root end filling material in prepared dog teeth after 10 weeks.
The presence of cementum and fibrous capsules was a frequent finding after 10 weeks on the surface of the MTA, but not with amalgam.[61] In another cell viability assay, freshly mixed or set MTA were both be less toxic than both Super EBA and amalgam. Others have found MTA less toxic to human PDL cells than Super-EBA and less toxic than freshly mixed amalgam.[61]

Gilheaney et al, evaluated apical leakage using different angles of apical resection and depths of retrograde filling. They found out that increasing the depth of a retrograde filling significantly decreased apical leakage, while increasing the bevel of the root end resection increased leakage. The minimum depths for a retrograde filling are 1, 2.1, and

2.5mm for 0°, 30°, and 45° bevels respectively.[63] Song et.al evaluate the clinical outcomes of endodontic microsurgery when Super EBA and MTA were used as root-end filling materials in a prospective randomized controlled study. A total of 192 teeth were examined at the 1 year follow-up; 102 teeth were in the Super EBA group, and 90 were in the MTA group. The overall success rate was 94.3%. No significant difference was found between success rates of Super EBA and MTA when a standardized surgical procedure is followed.[64]

In a clinical and radiographic outcome study by Shinbori et al, in root-end surgery when EndoSequence BC Root Repair (ES-BCRR) was used as the root-end filling material the overall success rate was 92.0%. None of the prognostic factors, including age, sex, tooth position, size of periapical radiolucency, presence of a sinus tract, preoperative symptoms, and retreatment previous to surgery, appeared to have any significant effects on the outcome.[65]

Kang et al, evaluated and compared the clinical and radiographic outcomes of nonsurgical endodontic retreatment and endodontic microsurgery by a meta-analysis. In this study Endodontic microsurgery and nonsurgical retreatment had stable outcomes presenting 92 and 80 % of overall pooled success rates, respectively. The microsurgery group had a significantly higher success rate than the retreatment group. When the data were organized and analyzed according to their follow-up periods, a significantly higher success rate was found for the microsurgery group in the short-term follow-up (less than 4 years), whereas no significant difference was observed in the long-term follow-up (more than 4 years).[66]

In a prospective periapical microsurgery study by Tawil et al, 155
teeth were treated using periapical microsurgery and modern microsurgical protocols in a private practice setting. They showed a significant superior clinical outcome for intact roots when compared with roots with dentinal defects at both 1 year and at 3 years postoperatively.[67]

All of the above considerations show the need for endodontic surgical procedures with some of the complications that may confound treatment. A knowledge base of bone and tooth dimensions in the surgical area may aid the dental practitioner when a CBCT is not available.

OBJECTIVES

Success of endodontic microsurgery is dependent on several factors. One of these factors is a thorough knowledge of anatomy in area we are performing the surgery. Others include the skill and preparation of the practitioner and the materials used. Although a current CBCT will provide the most accurate information for an individual patient, a CBCT may not be available, or may be cost prohibitive for the patient. Periapical radiographs may be taken for root location, but this supplies little information for the proximity of the sinus, the depth of bone over the site of root resection, or the dimensions of the root. A knowledge base of these measurements will aid the practitioner in these surgical situations.

Having more accurate measurement of root and buccal cortex thickness at the intended root resection level as well as the distance between the apex of the roots and proximity to the sinus will be helpful to the practitioner performing the root end resection.
The objectives of this study were to measure 1) the buccolingual (BL) and mesiodistal(MD) thickness on maxillary molar roots at the preferred level for root resection(3mm) 2) The distance between the root apices of the 1st and 2nd molars. 3) The proximity of each root apex to the maxillary sinus.

MATERIALS AND METHODS

The Institutional Review Board at the University of Minnesota approved the present study. 155 CBCT scans using the Next Generation i-CAT® (Imaging Sciences, Hatfield, PA)were collected from the University of Minnesota Oral and Maxillofacial Radiology. Of the 155 patient CBCT scans, 46 were from male and 109 from female patients. i-CAT Vision software was used to evaluate the maxillary molars and the adjacent anatomical structures. The scans were obtained from a database of images taken for diagnostic purposes or presurgical evaluation, unrelated to the present study.

Exclusion criteria for the study were:

1) More than one maxillary posterior tooth missing per side excluding third molars,

2) Significant periodontal disease/bone loss,

3) C shape molar

4) Fused roots

5) Resorption of any maxillary tooth

6) Artifacts of any kind impeding identification of anatomic structures.

7)- Mixed or primary dentition.

Scans had a field of view (FOV) of 170mm with 0.3mm resolution, 62 had a FOV of 130mm with 0.25mm resolution, and 36 had a FOV of 60mm with 0.2mm resolution.

Patient, sex, date of birth, and date the scan were recorded. Two graduate endodontic residents evaluated the CBCT scans. The examiners were calibrated for radiographic interpretation of the scans. To prevent eye fatigue, no more than 3 consecutive scans were completed by one examiner without a break period. The scans were viewed and evaluated on a Dell 24-inch non-glossy monitor with a Dell Optiplex 9010 WorkStation (Dell Inc, Round Rock, TX), using the i-CAT Imaging System Software (i-CAT, Imaging Software Sciences International Inc, Hartfield, PA). The examiners had the ability to magnify the images, and change the viewing settings, such as density, contrast and sharpness, in order to enhance visibility and identification of the examined structures. Cross-sectional slices from the "implant screen" view mode were used to complete all the measurements at the radiographic apex of each maxillary first or second molar present, as well as the measurements of the maxillary sinus to apices. The software allowed recording of linear measurements of the CBCT slices with a resolution range of 0.2mm to 0.3mm.(Figure 1)

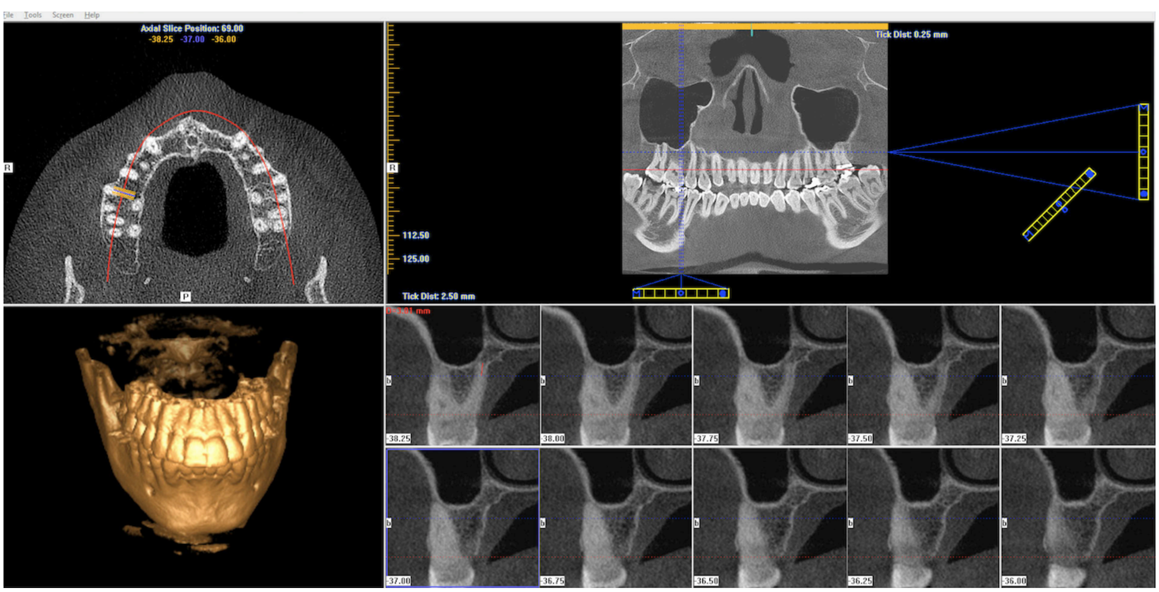


Figure 1- Implant screen of CBCT

In order to perform the measurements at the 3.6 mm from the apex level (optimal level for root canal resection of the MB root of first molars is 3.6 mm from the apex, and for all other canals 3 mm for the rest of the roots) line was drawn along the long axis of the tooth, extending from the radiographic apex to 3.6 for MB of first molar and 3 for the rest of the roots (red line on *Figure 2*). Because of limitations related to image resolution, when the line drawn from the apex could not be exactly 3.6 or 3 mm, the closest measurement was accepted. The range of the accepted measurements was between 3 – 3.9 mm.

In the sagittal view the closest distance from the apex to sinus was measured in the sagittal cross section. (Blue line on Figure 2)

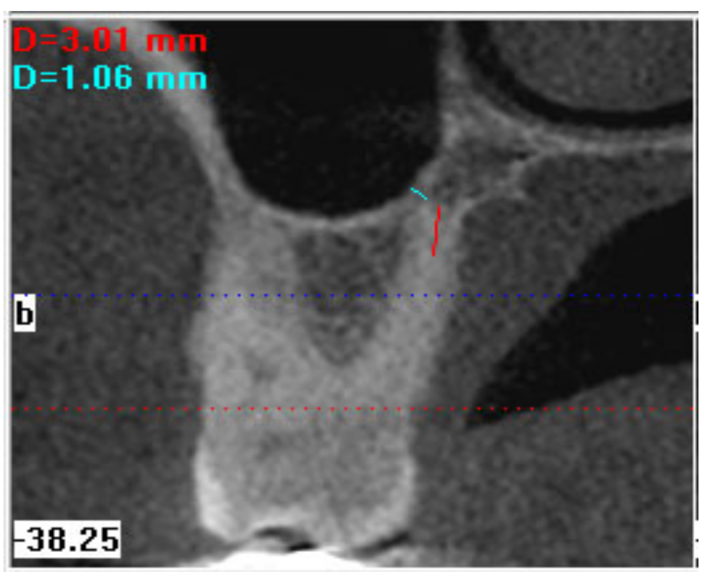


Figure 2: Measurement 3mm from the apex and distance from the sinus

If sinus thickening greater than 3 mm or any kind of sinus abnormality such as mucus retention cyst polyp or obliteration was detected, it was recorded, but not specified. Since this study was only a radiographic study and no clinical examinations performed, we were not able to identify the relation between the sinus pathology and teeth causing the pathology. The thickening was measured in the sagittal view. The buccal and palatal plate thickness, mesiodistal and buccolingual root thickness was measured in axial view indicating 3.6 for MB or 3 mm for the other roots. In each cross section the largest measurement and the closest distance to the adjacent root or bone was used. (figure 3)

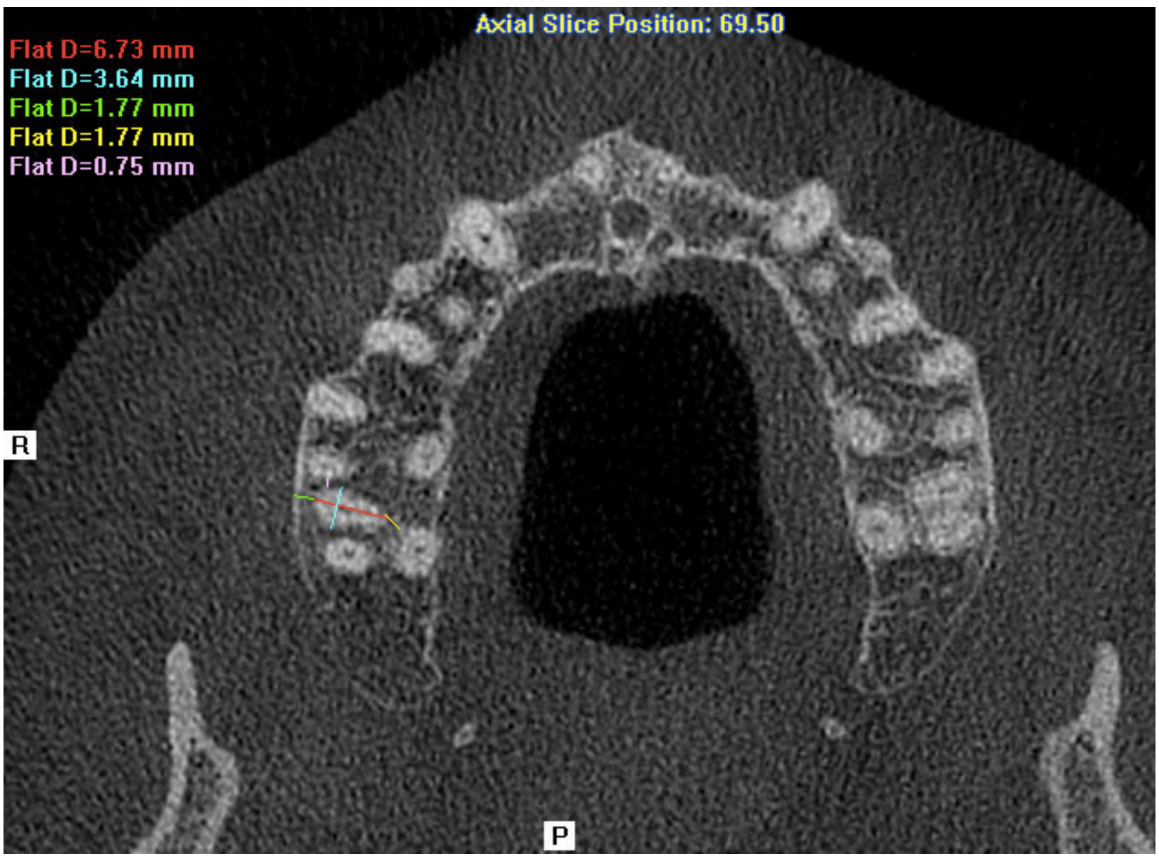


Figure 3 B-L,M-Distance between MB root and palatal root and buccal bone thickness. The MD blue and BL red line. Buccal plate thickness BP to RS root surface green line, Distance between the buccal and palatal root yellow line.

Palatal plate (PT) thickness was measured at the shortest distance between (PB) to root surface (RS) in palatal side of the root. And buccal plate was measured the same at the buccal side of the root. Due to low resolution of some of the scans when the buccal or palatal bone was too thin to be measured or the root appeared to be outside of the buccal or palatal plate, zero was recorded.

Since the software did not allow drawing the line perpendicular we had to draw a line diagonal and this might have led to an increase in the experimental measurements compared to actual clinical measurements.

RESULTS

CBCT scans (n=155) were used in this study for evaluation of maxillary molars and associated areas in the maxilla. The data recorded for each scan included sex, date of birth, date of scan, field of view (FOV), and resolution. Twenty-two scans had a field of view (FOV) of 170mm with 0.3mm resolution, 34 had a FOV of 130mm with 0.25mm resolution, and 101 had a FOV of 60mm with 0.2mm resolution. The demographic analysis revealed 109(70%) of the study population was female (n=109) and 46(29%) were male (n=46). The age of the study population ranged between 13 to 87 years old, There were 45 patients under the age of 35; 62 patients between the ages of 36-59, and 48 patients age 60 and above.

As mentioned in the exclusion criteria, scans were not included if more than one maxillary molar or premolar was missing, so scans with less than 3 posterior teeth were excluded. C shape molars were also excluded from this study since due to limitations accurate measurements of those teeth was not possible.

Thickness of buccal and lingual plate over the root of first and second molar 3 mm from the apex for all the roots and 3.6 mm for MB of first molar are presented in Table 1.

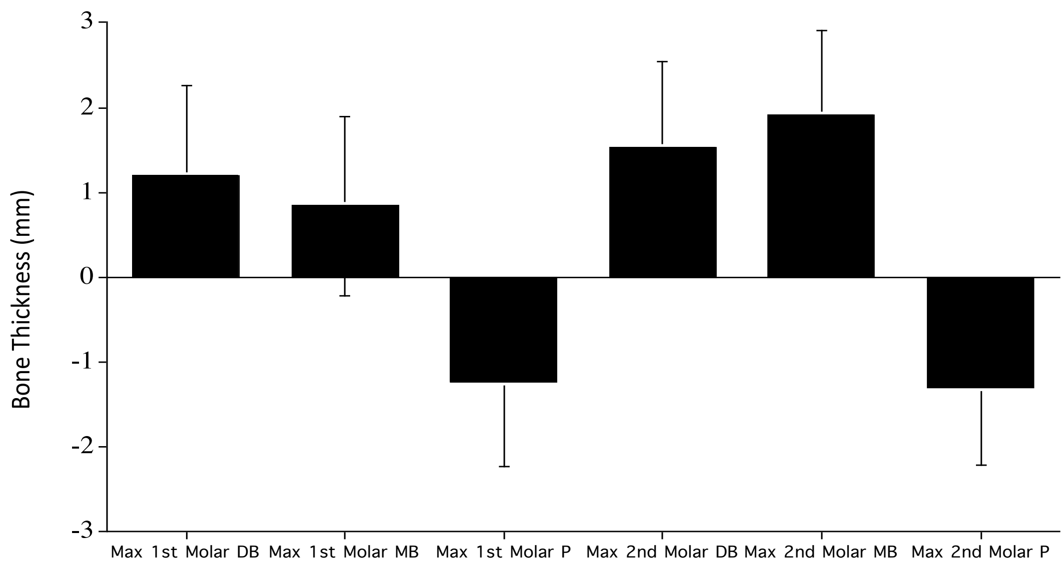


Figure 4:Buccal and Palatal bone thickness

Tooth#/Root		Buccal cortex to root surface (BC/PC to RS)(mm)
Mx 1st molar DB	Mean SD	1.19 1.07
Max 1st molar MB	Mean SD	0.84 1.06
Max 1st molar P	Mean SD	1.24 0.99
Max 2nd molar DB	Mean SD	1.52 1.02
Max 2nd molar MB	Mean SD	1.91 1.00
Max 2nd molar P	Mean SD	1.31 0.91

Table 1 Thickness of buccal and palatal cortical plate 3/3,6 mm from the apex for first and second maxillary molar.

As it is shown in Table 1, the thinnest bone is over the MB root of first molar at the resection level and the thickest bone is over the MB root of the second molar. Data in this table shows that thickness of palatal bone over the palatal root of second molar is slightly more then the first molar. From this data, we may assume that the best approach for buccal roots is from the buccal and for palatal roots, from palatal.

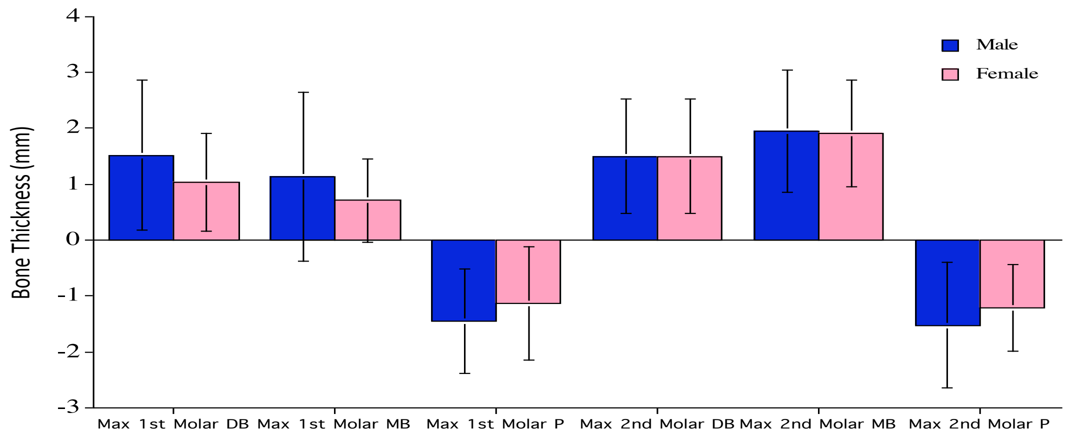


Figure 5:Buccal and Palatal bone thickness comparing Male *vs* Female

Tooth#/Root			BC to RS/PC to RS (mm)
Mx 1st molar DB	Male	Mean/SD	1.52/1.34
	Female		1.04/0.88
Max 1st molar MB	Male	Mean /SD	1.14/1.51
	Female		0.71/0.75
Max 1st Molar P	Male	Mean/ SD	1.45/0.94
	Female		1.13/1.02
Max 2nd molar DB	Male	Mean /SD	1.5/1.02
	Female		1.5/1.02
Max 2nd molar MB	Male	Mean/ SD	1.95/ 1.1
	Female		1.91/0.96
Max 2nd molar P	Male	Mean /SD	1.52/1.13
	Female		1.21/0.77

Table 2: Thickness of the buccal and cortical plate in male and females 3 mm at the resection level.

As shown in Table 2 the thickness of buccal bone at the preferred resection level is slightly greater on buccal roots of second molar compared to first molars in both male and female patients so we can assume that as we go posteriorly the thickness of the bone that we need to remove for our osteotomy increases. Palatal bone 3 mm from the apex is also thicker over second molars compare to first molars, and we can make a similar assumption for palatal osteotomy. Interestingly all these measurements are slightly greater for males when comparing male to female.

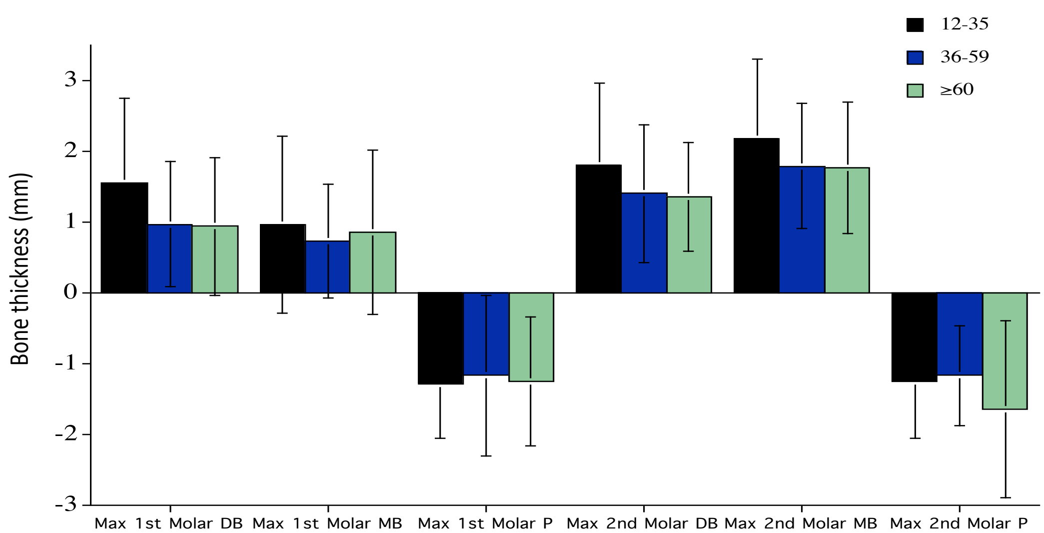


Figure 6: Buccal and Palatal bone thickness comparing 3 age group

Tooth#/root		BC-RS	PC-RS	B-L width	M-D width
Max 1st DB	12-35 36-59 >60	1.56 / 1.19 0.97 / 0.89 0.94 / 0.97		4.30 / 1.12 4.27 / 0.94 4.28 / 1.18	2.83 / 0.51 3.06 / 0.75 3.13 / 0.58
Max 1st molar MB	12-35 36-59 >60	0.96 / 1.25 0.73 / 0.81 0.85 / 1.16		5.56 / 1.12 5.63 / 0.99 5.40 / 1.30	3.16 / 0.56 3.17 / 0.70 3.54 / 0.69
Max 1st molar P	12-35 36-59 >60		1.28 / 0.78 1.17 / 1.14 1.25 / 0.91	4.01 / 0.83 4.09 / 0.87 4.13 / 1.18	4.26 / 0.71 4.34 / 0.74 4.44 / 0.92
Max 2nd molar DB	12-35 36-59 >60	1.80 / 1.16 1.40 / 0.98 1.36 / 0.77		4.00 / 0.76 4.02 / 0.83 4.15 / 1.07	2.83 / 0.74 2.86 / 0.57 3.00 /0.72
Max 2nd molar MB	12-35 36-59 >60	2.17 / 1.13 1.79 / 0.89 1.77 / 0.93		5.12 / 1.18 5.33 / 1.14 5.20 / 1.54	2.91 / 0.72 3.02 /0.70 3.24 / 0.62
Max 2nd molar P	12-35 36-59 >60		1.25 / 0.81 1.17 / 0.7 1.64 / 1.25	3.73 / 0.72 3.77 / 0.81 4.07 / 0.91	3.76 / 0.76 3.84 / 0.66 4.02 / 0.64

Table 3: B-L and M-D thickness of roots and buccal and palatal cortex of maxillary 1st and 2nd molars 3/3.6 mm from the apex

There was no pattern in BL thickness of the roots between the 3 age groups.

For MD thickness as you can see here older people had thicker MD compared to younger and middle age group so the MD thickness was age dependent. As shown in this Table there is a slight increase in M-D thickness 3/3.6 mm from the apex with increased age, but there is no specific pattern in other measurements in this table.

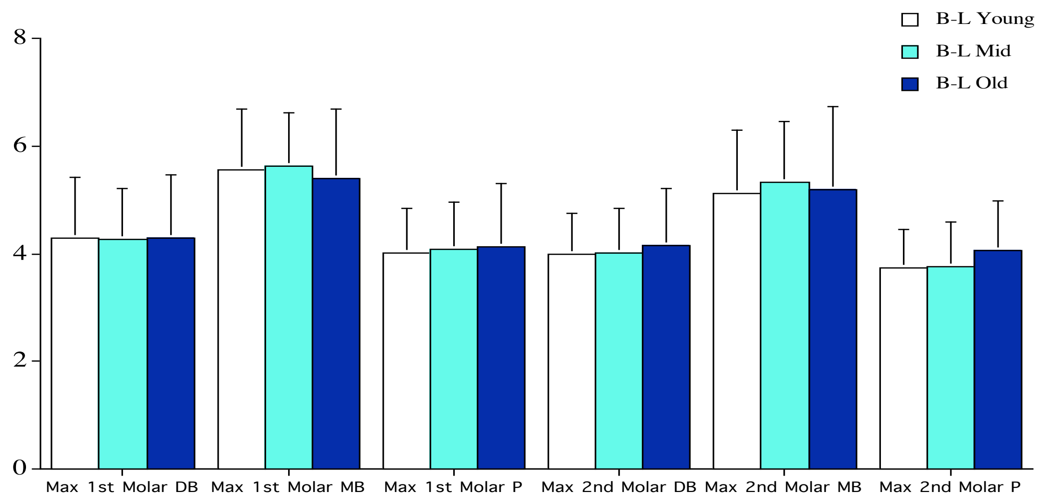


Figure 7: B-L root thickness comparing 3 age groups

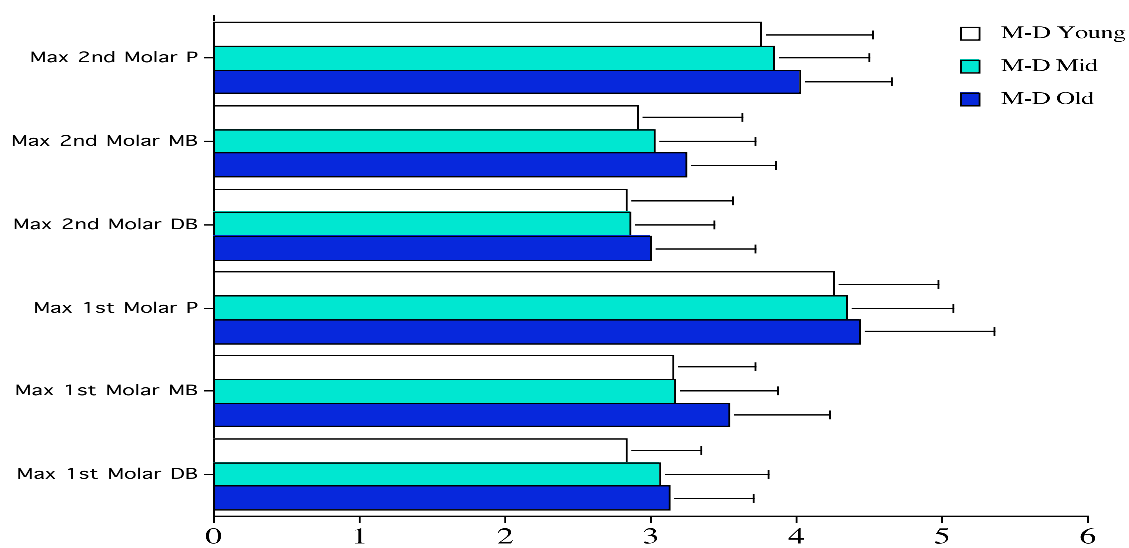


Figure 8: M-D root thickness in 3 different age groups

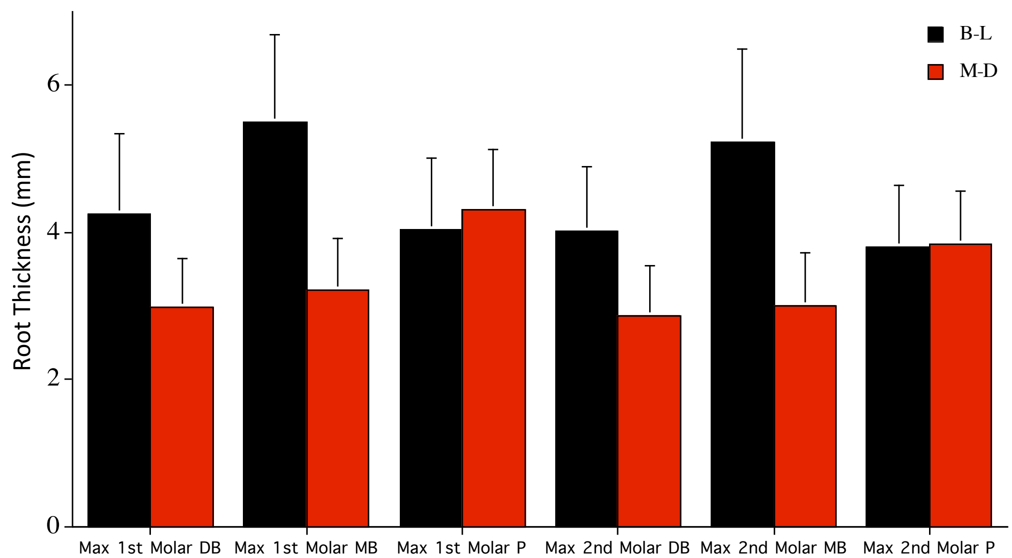


Figure 9: B-L and M-D root thickness

Tooth/Root		B-L width	M-D width
Mx 1st molar DB	Mean SD	4.24 1.11	2.98 0.67
Max 1st molar MB	Mean SD	5.49 1.19	3.22 0.69
Max 1st molar P	Mean SD	4.04 0.97	4.31 0.81
Max 2nd molar DB	Mean SD	4.02 0.88	2.87 0.68
Max 2nd molar MB	Mean SD	5.22 1.27	3.01 0.71
Max 2nd molar P	Mean SD	3.81 0.83	3.84 0.72

Table 4: M-D and B-L thickness of maxillary first and second molar 3 mm from the apex

As seen in Table 4 the thickest bucco-lingual width belongs to MB root of first molar and the palatal root of the maxillary second molar has the smallest thickness bucco-lingualy. The greatest mesiodistal thickness belongs to palatal root of first molar while the smallest is DB root of maxillary second molar.

Tooth/ Root	DB of second to MB of second	MB of second to DB of first	DB of first to MB of first	Palatal of second to palatal of first
MM/SD	1.00 0.79	1.49 0.96	1.81 0.92	3.74 1.43

Table 5: Distance between first and second maxillary molar

As we can see in Table 5 shows that the closest root proximity belongs to MB and DB roots of second molar. These numbers show the importance of precision in root resection in order to avoid damage to neighboring roots.

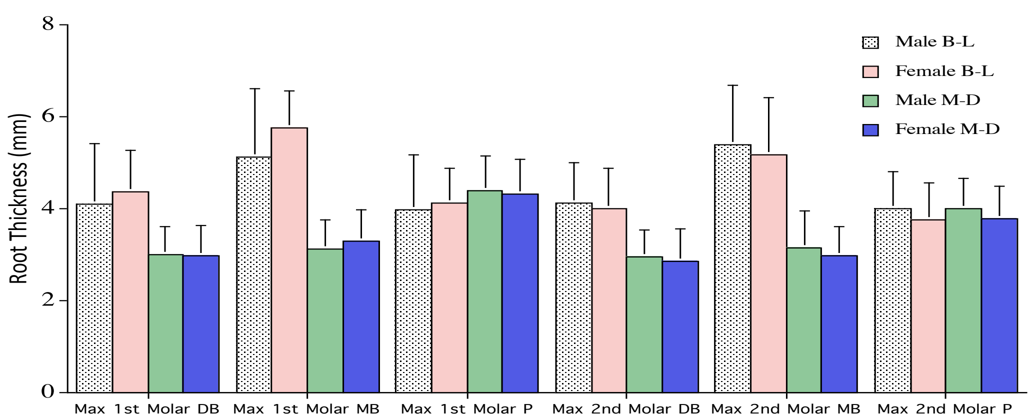


Figure 10: B-L and M-D root thickness comparing Male and Female

Tooth#/Root			B-L width	M-D width
Mx 1st molar DB	Male Female	Mean / SD	4.09 / 1.32 4.37 / 0.9.	2.99 / 0.61 2.98 / 0.66
Max 1st molar MB	Male Female	Mean / SD	5.11 / 1.49 5.75 / 0.81	3.13 / 0.63 3.29 / 0.69
Max 1st molar P	Male Female	Mean/ SD	3.98 / 1.20 4.11 / 0.77	4.38 / 0.77 4.31 / 0.77
Max 2nd molar DB	Male Female	Mean / SD	4.13 / 0.86 4.00 / 0.87	2.95 /0.58 2.85 / 0.70
Max 2nd molar MB	Male Female	Mean / SD	5.39/1.28 5.18/1.23	3.15 / 0.79 2.97 / 0.65
Max 2nd molar P	Male Female	Mean / SD	3.99 /0.81 3.75 / 0.80	3.99 / 0.67 3.79 / 0.70

Table6: B-L width and M-D width 3 mm from the apex in Male and Female

As can be seen in Table 6, B-L width of MB root of 1st molars 3.6 mm from the apex is less than seen in 2nd molars from males but this thickness is greater in first molars of females.B-L Thickness of DB in maxillary 1st molar 3 mm from the apex is also less than 2nd molars in males, but this number is larger in female patients. Male population of this study had thicker Palatal roots 3 mm from the apex in second molars compare to first molars ,while females had thicker palatal root 3 mm from apex in first molars. As far as

M-D thickness, male population of this study had thicker M-D dimension than female 3 and 3.6 mm from the apex in all the roots included in this study.

Tooth# / Root	BC-RS (mm)(BL)		Root width (mm)(BL)		Total resection width (mm)	
	DB	MB	DB	MB	DB	MB
Max 1st molar	1.19 1.07	0.84 1.06	4.24 1.11	5.49 1.19	5.43	6.33
Max 2nd molar	1.52 1.02	1.91 1.00	4.02 1.11	5.49 1.19	5.52	7.40

Table 7: Total resection in mm for MB and DB roots Maxillary 1st and 2nd molar

Tooth/ Root	B-L width Of Palatal root	Palatal cortex	Total resection width
Max 1st molar	4.04 0.97	1.24 0.99	5.28
Max 2nd molar	3.81 0.83	1.31 0.91	5.12

Table 8: Total resection in mm for palatal roots of Maxillary 1st and second molar

Looking at data from both Table 7 and 8, the greatest resection depth of 7.40 mm is on MB of second molar showing the large size of osteotomy when performing the RER /REF on that root.

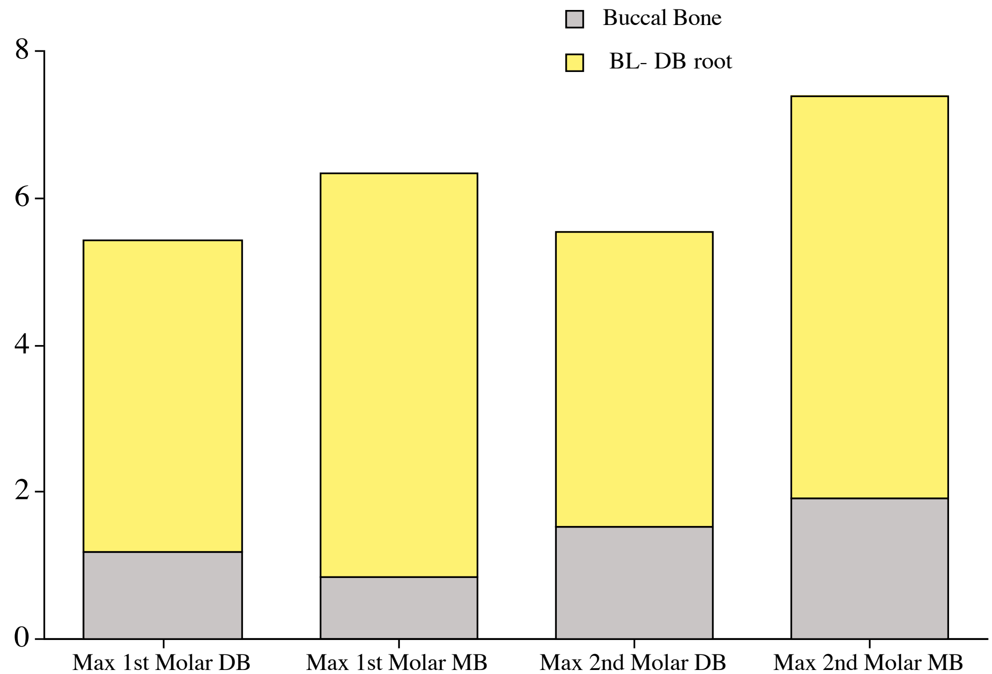


Figure 11. Total resection depth for buccal roots of 1st and 2ndf maxillary molars.

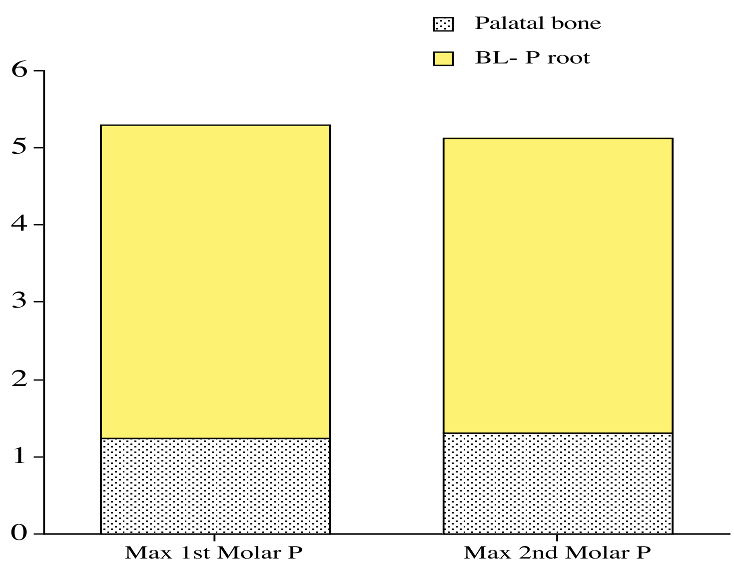


Figure 12: Total resection depth for palatal roots of 1st and 2nd maxillary molars.

Of the 155 scans 57(36.8%) showed sign of sinus pathology. Thickening more than 3mm, sinus obliteration and mucus retention cyst was recorded as sinus pathology. The average thickening in this study was 7.2mm. Due to only examination of radiographic data with no clinical data, we could not find an association between sinus and dental pathology. However in a total of 27 patients, or 47% of the time, sinus pathology occurred adjacent to teeth with apical radiolucencies. In three patients, more than one tooth with a periapical radiolucency was adjacent to the area of the sinus thickening, yielding a total of 31 teeth in 27 patients. Teeth with recorded apical radiolucencies adjacent to the area of sinus pathology 18 (58.1%) were first molar, 7(22.6%) of them were second molars.

Tooth#/root	Distance from the sinus
First molar DB	1.64/5.30
First molar MB	2.71/1.16
First molar P	1.31/1.79
Second molar DB	0.95/1.28
Second molar MB	0.66/1.07
Second molar P	0.66/1.07

Table: 9 Distance from the sinus

Tooth#/root		Distance from the sinus
First molar DB	12-35 36-59 >60	1.86 / 8.4 1.41 / 1.72 1.56 / 1.86
First molar MB	12-35 36-59 >60	1.39 / 2.04 1.58 / 1.93 1.76 / 1.34
First molar P	12-35 36-59 >60	1.17 / 1.90 1.44 / 1.90 1.26 / 1.31
Second molar DB	12-35 36-59 >60	0.91 / 1.46 1.00 / 1.17 0.88 / 1.21
Second molar MB	12-35 36-59 >60	0.49 / 1.12 0.73 / 0.96 0.81 / 1.20
Second molar P	12-35 36-59 >60	1.02 / 1.28 1.22 / 1.44 1.15 / 1.78

Table 10: Distance from root apex to sinus floor in Maxillary 1st and 2nd Molars in 3 different age groups

As this table shows, the MB root of maxillary second molar has the closest proximity to the maxillary sinus in all of the age groups. The farthest root from the sinus was DB root of first molar in 12 to 35 year olds and the shortest distance was MB root of maxillary second molar of the same age group.

Tooth#/root		Distance from the sinus
First molar DB	Male Female	2.16 / 9.18 1.36 / 1.91
First molar MB	Male Female	1.57 / 1.71 1.54 / 1.95
First molar P	Male Female	1.05 / 1.65 1.42 / 1.85
Second molar DB	Male Female	0.86 / 1.15 0.98 / 1.33
Second molar MB	Male Female	0.61 / 0.96 0.68 / 1.11
Second molar P	Male Female	0.94 / 1.12 1.21 / 1.53

Table 11: Distance for root apex of maxillary 1st and 2nd molars to sinus floor in male and female.

As can be seen the farthest root from the sinus was DB of first molar in male patients and the closest was MB root of second molar in the same population in this study. In general there was no special pattern in this study for distance between the sinus and root apex between male and female in this study.

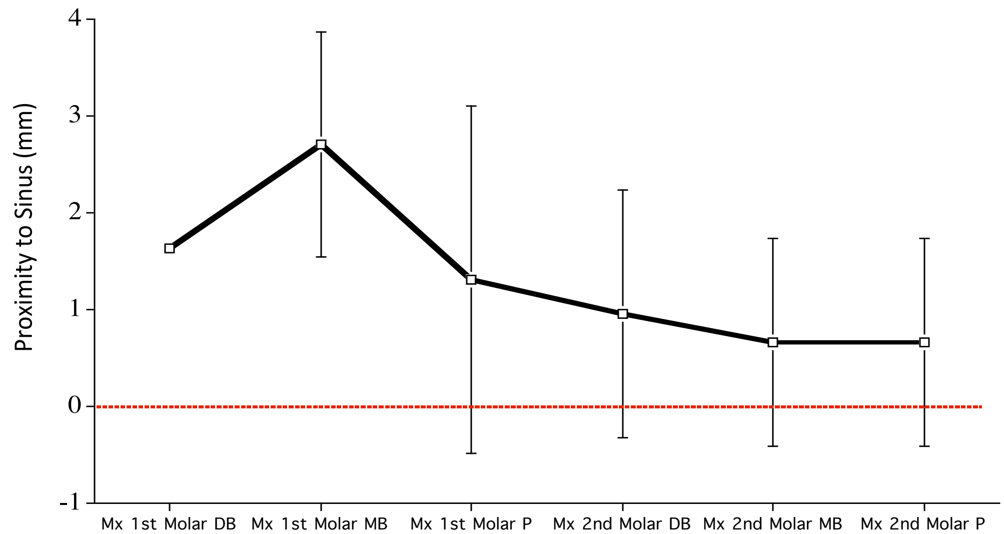


Figure 13: proximity of root apices to sinus

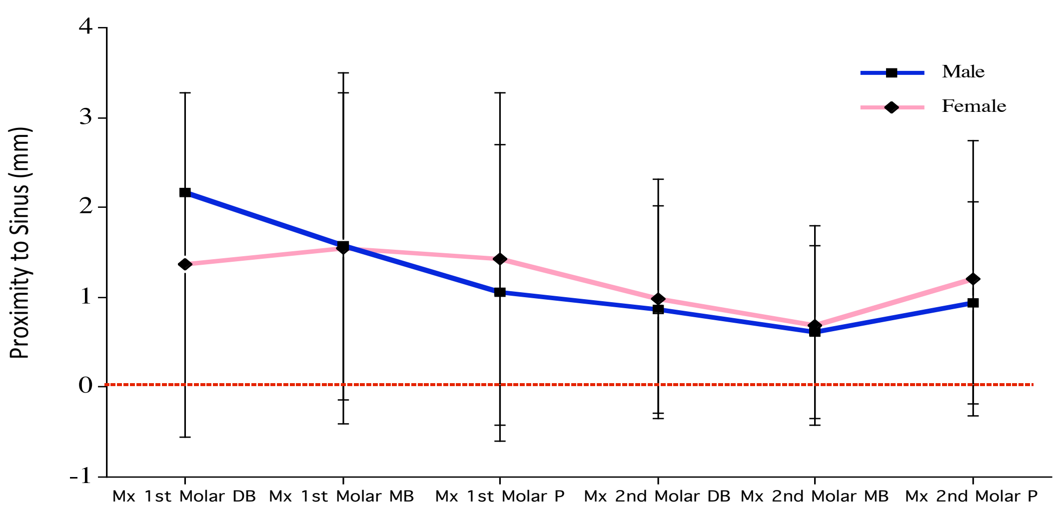


Figure 14: Proximity of root apices to sinus comparing male and female

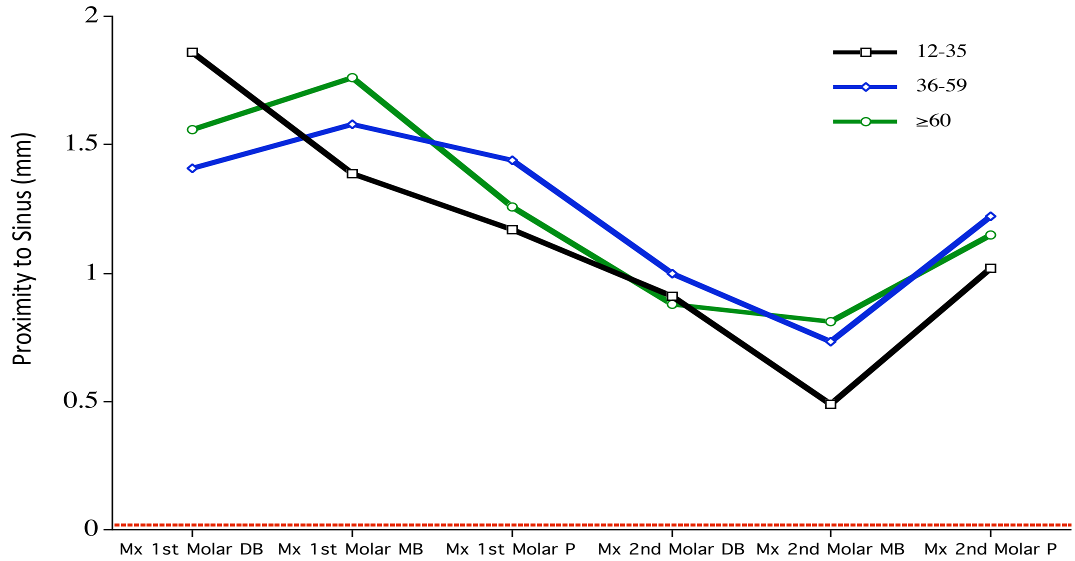


Figure 15: Proximity of root apices to sinus comparing 3 different age groups

Discussion

The purpose of this study was to use CBCT scans to provide information regarding anatomic dimensions of the maxillary first and second molars at root resection levels of 3-3.6 mm from the apex and distance from the apices of their roots to maxillary sinus while comparing these numbers between male and female and also between 3 different age groups. Also recorded was the presence of sinus abnormalities such as thickening more than 3mm, obliteration and mucus retention cyst, but we did not specify the type of that pathology.

In this study we used CBCT scans. According to Patel et al, increased diagnostic data with CBCT should result in more accurate diagnosis and monitoring, and therefore improve decision making for the management of complex endodontic problems.[38] In a retrospective cohort study by Vogiatzi et al, they found CBCT to be used primarily to evaluate bony anatomy and to screen for overt pathology of the maxillary sinuses prior to dental implant treatment.[45]

In about 50% of the population, the sinus expands into the alveolar process, placing it in close relation to the roots of the premolars and molars. During surgery of maxillary posterior teeth, the sinus is at risk for exposure as a result of surgical procedures or by pathologic invasion.[16] According to a review article by Watzeck et.al, sinus perforation occurs in 28% of maxillary endodontic surgery cases. For prevention, they recommended elevating the sinus with a blunt elevator in cases where the sinus is between the roots to prevent perforation of the Schneiderian membrane. All these findings stresse the importance of the anatomic knowledge of the area for the surgeon before the endodontics microsurgery. Our data for distances between the sinuses to root apices of maxillary first and second molars will assist the surgeon to better predict the chances of sinus perforation prior to endodontic microsurgery .

In this study, 36% of the scans showed signs of sinus pathology, including sinus thickening more than 3mm, sinus perforation and mucus retention cyst. Using CBCT scans Maillet et .al reported that changes in the maxillary sinuses appear to be associated with periapical pathology in greater than 50% of the cases. They developed radiographic diagnostic criteria for sinusitis of odontogenic origin. Due to lack of clinical data we could not find an association between sinus and dental pathology.

However, in this study, sinus pathology was noted in 36.8% of the patients.

Of all those teeth that were next to the area of sinus pathology, 18 (58.1%) were first molars, and 7(22.6%) were second molars. These findings confirms the findings of Maillet et.al that teeth involved in sinus pathology were mostly first and second molars. Thunthy reported that maxillary sinusitis may or may not be dental in origin. If dental in origin (approximately 10%), it may be the result of periapical infection, periodontal disease or perforation during surgery. This number is lower than the 50% that was reported by Maillet et.al. In our study there was dental pathology next to the area of sinus pathology 47% of the time.

Eberhardt et al looked at CT images both *in vivo* and *in vitro* and they reported NSD between either measurement. They looked at the images in coronal axial and sagittal view, but in this study we did our measurements using the sagittal view for this portion. Unlike this study, Eberhard et al did not mention the age or the sex of their participants, but they also looked at the buccal bone thickness over the apex of maxillary molars while this study examined the thickness of bone at the preferred resection level where the osteotomy is performed. They found the buccal cortex to be the thickest at the apex of MB root of second molar (4.25mm) which confirms our finding of the thickest bone on MB of second molar at resection level (1.91mm). Their founding that MB of maxillary second molar is closest to the sinus also agrees with our findings for the same tooth.

This study did not look at ethnicity. In Ok et al study on Turkish population they looked at 894 CBCT scans which is relatively larger than our sample size and in their study they adopted a classification for proximity to sinus. Type I (roots that were penetrating the sinus) occurred mostly in palatal root of first molar, In our study closest root to the sinus was MB root of the second molar.

Type II (were the roots that contacted the sinus floor) in MB of second molars, and type III (roots extended below the sinus floor) in MB and DB of first molar. As far as the 3 different age group in our study, the closest distance to the sinus belonged to MB root of the second molar in the 12 to 35 year group (0.49mm), and when comparing male to female measurements, the closest distance was seen in the MB root of second molars in males (0.61mm).

In Ok et al study males of second decade had the closest proximity to sinus and were more susceptible to undesirable results, which agrees with our findings.
Kilic et al showed that DB root tip of second molar had the closest proximity to the sinus floor while in our study MB root tip had the closest proximity. In their study they showed no statistically significant differences between the right and left side measurements or between female and male patients.

Because of the very close anatomical relationship that exists between the maxillary posterior teeth root tips and the sinus floor, endodontic surgery of molars can result in oroantral communication that can allow bacteria from infected periapical tissue, resected root tips, or surgical debris to be displaced into the sinus and cause acute or chronic sinusitis.[24] Surgical treatment of posterior teeth is also complicated by the restricted space of the oral vestibular region, which in turn makes it difficult for gingival flap reflection.[24]

This study is the first that has used CBCT images to evaluate root thickness and distances between roots in maxillary molars. The resection level was at 3 mm for all the roots according to Kim except MB of first molar which was set at 3.6 mm according to Degernes and Bowles. In the latter study the authors found out that the isthmus tissue increased greatly at 3.6 mm from the apex, suggesting optimal root resection at this level.[14]

Like Eberhardt et al, Jin et.al also looked at buccal bone plate over the apex of maxillary and mandibular teeth. Thickness of the buccal bone over the mesio-buccal and disto-buccal roots of the second molar was thicker than the first molar (1.91 mm and 1.52 mm, respectively).

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Our data for thickness of buccal cortex over the MB root of first molar was 0.84 mm and for the DB root was 1.52mm. When comparing these data with Jin et.al, bone thickness at the apex is relatively greater than at 3 mm resection level. They also found the average thickness for palatal cortex of first molar at the level of the apex to be 3.15 and this thickness for second molar was 3.08. In our study, palatal cortex at 3 mm resection level was 1.24 mm for first and 1.31for second molar. These differences are easily explained by the apex of the tooth being the narrowest portion of the tooth. With regard to differences between males and females, Jin et al also reported that most of the maxillary and mandibular teeth showed thicker bone plates in men than in women, but this disparity was not found to be statistically significant ($p > 0.05$). Therefore, it seems unnecessary to recommend or establish different apical surgery protocols for men and women and this confirms the findings of our study on bone thickness in males vs. females.

The palatal cortex was the thickest over the maxillary second molars in males with a mean of 1.52 mm and thinnest over palatal roots of maxillary molars in females with the mean of 1.13 mm. Looking at these numbers we can assume that the best approach for surgical resection of palatal roots in maxillary molars is from the palatal.

In many instances, however, the lingual approach is extremely restricted, not simply because of the poor accessibility inherent in the approach, but also by the adjacent sensitive anatomical structures, most notably the greater palatine foramen. Therefore, knowledge of the thickness of the buccal and palatal cortex is of prime importance when planning apical surgery.

In general, thickness of buccal bone increases from the MB root of first molars posteriorly toward the MB root of second molars, and then decreases towards the DB root of second molars. The MB root of maxillary first molars from females in this study had the thickest B-L width with the mean of 5.75 mm, which was slightly thicker than the same root in males and the same root had the thinnest buccal cortex at the resection level with the mean of 0.71mm we can assume that as BL width of the root increases the buccal cortex over that root gets thinner.

The high prevalence of a second canal in MB root of first molars, which was mentioned in several studies (eg. by Stropco et.al) to be 73% can be a the reason the thickness of this root. This thickness can cause challenges while resecting this root.
According to Hoen et.al the most commonly retreated tooth is the maxillary first molar and missed canals were mostly located in 42% of MB root of patients in that study.
Allen also found that most frequently missed canals were often in maxillary first molars and this happens mostly in patients 40 years and older. In clinical situations where these canals are not found and left untreated, endoodontic microsurgery is a valid option to resolve this problem.

The thinnest B-L width belonged to the palatal root of second molar in females
We did not find any pattern for the M-D or B-L thickness between male and female in this study.

Looking at different age groups, the only pattern was seen in M-D thickness of all the roots of molars and B-L width of palatal roots, which both increased with age.
We know from a study by Stein, as age increases, the width of the cementum (mean 0.492mm), the deviation of the foramen opening from the apical vertex (mean 0.476), and the width of the foramen opening (mean 0.540mm) all increase. The width at the CDJ is independent of age and appears to remain constant (mean 0.189). In this study, we also found MB and DB roots of second molars are the closest in proximity to each

other compared to other roots of first and second molars (with mean of 1.00 mm) and this can play an important role for the surgeon during root resection since our goal is is to prevent trauma to neighboring roots during the microsurgery. Trauma can be a contributing factor in external root resorption.

According to Goldman et.al when interpreting conventional periapical radiographs for success and failure criteria, presence or absence of rarefaction, examiners agreed only 47% to73% of the time. Interestingly, even when the same examiner evaluated the same conventional periapical image 6 months later, they agreed with themselves 75 to 83% of the time. These findings were confirmed for digital periapical radiography by Tewary et al, who noted that the interpretation of a dental radiograph (conventional or digital) is subjective, and the factors that appeared to have the most impact were the examiner's experience and familiarity with a given digital system.[69,70]

In this study, we did not specify the pathosis of the sinus. Abnormalities detected in this study included but not limited to retention cysts sinus thickening mucocel and any other abnormality.

Conclusion

Overall, knowledge of the maxillary bone and posterior tooth /root thickness, distance to sinus and root proximity can provide the surgeon with a knowledge base. Application of CBCT can aid endodontists in performing more predictable RER/REF procedures. This study is the first to provide average tooth and bone thicknesses at the resection level for root end resections.

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