ANATOMICAL RELATIONSHIP OF THE INCISIVE CANAL TO STRUCTURES OF THE ANTERIOR MANDIBLE USING CONE BEAM COMPUTED TOMOGRAPHY

A THESIS
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

LAURA LOWERY MILROY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE

SCOTT B. McCLANAHAN

AUGUST 2013

ACKNOWLEDGEMENTS

Drs. Scott McClanahan, Michael Baisden, Walter Bowles, and Samantha Harris:

I would like to express my sincerest gratitude and deepest appreciation for your contribution toward my growth in the field of endodontics as well as your assistance in the formulation and completion of this project.

Dr. Mansur Ahmad:

I would like to acknowledge with much appreciation your crucial role in the support and completion of this project in a timely manner. Without your help, this thesis would not have been possible.

Drs. Daphne Chiona and Tyler Koivisto:

Thank you for your hours of sacrificed time gathering data after hours and over weekends. A special thank you to Dr. Koivisto for sharing your project with me.

DEDICATION

To my ever-supportive husband, Tyler:

Thank you for your unconditional love, support, and sacrifice in my pursuing and completing specialty training. Thank you for always believing in me and pushing me to reach for my dreams.

To my parents, Steve and D'Ann:

Thank you for instilling in me a sense of hard work and dedication, and the drive to succeed. Thank you for encouraging me to excel in academics and supporting me in my educational pursuits.

To my in-laws, Jim and Trina:

Thank you for you unconditional support of both Tyler and me. Thank you for being understanding of the time commitment and sacrifices needed to obtain specialty status.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The goal of root canal therapy is to prevent or resolve apical periodontitis. Contemporary endodontics is effective at achieving this goal with high success; however, apical periodontitis has been shown to persist in 14% of cases after initial therapy and in 18% of cases after orthograde retreatment.[1,2] If the technical aspects of the procedure have been performed correctly and apical periodontitis persists, surgical endodontic therapy should be considered.

Historically, endodontic surgery has been limited to anterior teeth where access has been considered adequate.[3] Periradicular surgery of anterior teeth generally involves less risk of damage to vital anatomic structures and less potential complications compared to posterior teeth.[4] However, surgery of mandibular anterior teeth is often more challenging than expected. The combination of a lingual root inclination, the need for a full resection of the root for preparation of a possible missed second (lingual) canal, and a perpendicular root-end resection, all increase the level of difficulty.[4] For a successful surgical procedure, it is important to establish the location and position of the root in the mandible as well as the morphology of the root and mandible.

Endodontic surgery may not be a viable option if the periodontal or restorative prognosis of a tooth is poor. Osseointegrated implants play a significant role in the rehabilitation of the dentition. Implant, apical, and other dentoalveolar surgery can cause neurosensory disturbances primarily affecting the inferior alveolar nerve or lingual nerve after treatment of posterior teeth. Generally, the anterior mandible has been considered a safe surgical area to place implants with high success and minimal complications.[5] The incisive nerve, a continuation of the inferior alveolar nerve anterior to the mental foramen, provides innervation to the anterior mandible and is often not considered in pre-surgical treatment planning. Lingual foramina, found on the lingual side of the mandible, are likely to be disregarded in the surgical process as well. Failure to adequately assess these adjacent neurovascular structures prior to surgery may cause undue complications. Although the anterior mandible tends to have fewer complications than the posterior mandible, there is still risk of damage to the neurovascular bundles leaving patients with transient or long-lasting neurosensory changes.[6]

Radiographic examination is an essential component of surgical planning. Knowledge of the precise anatomic topography by means of radiography is of utmost importance in avoiding potential complications. Conventional periapical and panoramic radiographs have historically been used for pre-surgical assessment. The amount of information gained from a conventional film is limited. As two-dimensional images they lose the third dimension, the bucco-lingual plane, and inherently superimpose anatomic structures. These problems have been overcome with the introduction of cone beam computed tomography (CBCT) into the field of dentistry. The benefits of three-dimensional CBCT are numerous. It can accurately provide important information for apical or implant surgery including the relationship of the root apices to anatomic structures, the thickness of the cortical plate, the presence of fenestrations, the inclination of the root, and the height and width of the mandible.[7]

In addition to its clinical uses, CBCT is a valuable research tool. Early anatomic studies were completed on cadavers. These studies have small sample sizes and are insufficient at providing normal distribution of the data.[8] More recently, medical computed tomography and magnetic resonance imaging have been utilized for dental research, but are also limited to small study populations as they are not frequently used for dental purposes.[9] Currently, CBCT is frequently utilized in dentistry providing a wealth of information available to researchers and allowing for larger populations to be studied.

LITERATURE REVIEW

Apical Surgery

The objectives of endodontic therapy include the elimination of microorganisms from the root canal system and subsequent placement of an effective seal to prevent microorganisms or their byproducts from penetrating into the periradicular tissues. Although conventional endodontic therapy has a high success rate, non-healing may occur. Orthograde retreatment is generally preferable to a surgical approach; however, when orthograde retreatment is not possible or has been unsuccessful, apical surgery may be necessary to retain the tooth.

Endodontic surgery aims to eradicate pathosis and regenerate lost tissues by sealing all portals of exit from the root canal system, eliminating bacteria and their byproducts from contaminated periradicular tissues, and providing a favorable environment for healing. This is accomplished through curettage of infected or inflamed granulomatous tissue, resection and removal of the infected or damaged root apex, and placement of a biocompatible retrograde filling.[10]

Historically a steep facial bevel of the resected root was required for access and visibility. This was inevitable with traditional techniques particularly in mandibular incisors possessing a lingual inclination.[11,12] Advances in endodontic microsurgery, particularly the surgical microscope and ultrasonic root-end preparations, allow the clinician to resect the root-end more perpendicular to the long axis of the root.[12] A perpendicular resection is more likely to include apical ramifications. At a level 3mm from the apex, 55% of mandibular incisors have been found to possess an isthmus compared to 20% and 30% at the 1mm and 2mm levels respectively.[12] The angle of the apical resection also influences leakage from along the interface of the retrograde filling and canal wall, and from open dentinal tubules at the resected root end.[10] Gilheany found that increasing the bevel of the resection increased apical leakage from around the retrograde filling as well as from permeable dentinal tubules.[10] By keeping the angle of the bevel on the root face to a minimum, the number of dentinal tubules that communicate with the periradicular region decreases.[13.14] Another advantage of a perpendicular root-end resection is that it offers a better distribution of stresses exerted on the apical region. This may reduce the propagation of apical fractures and provide a better environment for apical healing.[15]

An osteotomy must be created in apical surgery to gain access to the root apex. The bone thickness, shape of the mandible, inclination of the roots, and adjacent anatomical structures are all relevant factors in planning the osteotomy.[16] Two major concerns for clinicians are the position of the root apices within the mandible and proximity to vital structures. The buccolingual position of the root cannot be assessed with traditional radiographs. It would be advantageous for the clinician to know the average horizontal distances from the cortical plates to the root, the average width of the root, and its proximity to vital structures. Clinicians could use the average distance between the root apex and neurovascular bundle to assess the potential for nerve impairment.[17]

Course of the Inferior Alveolar Nerve

The course of the inferior alveolar nerve (IAN) within the mandible is important for dental anesthesia, root canal therapy, dental implants, third molar extractions, and any surgical procedure involving the mandible.[18,19] The IAN runs with the inferior alveolar artery though the infratemporal fossa and enters the mandible through the mandibular foramen. It courses through the mandible, from the lingual to the labial side, encased in the mandibular canal which divides into mental and incisive segments between the roots of the premolars.[20] The mental canal ends in the mental foramen while the incisive canal continues anteriorly below the incisor teeth carrying the incisive nerve.[21]

Anatomy of the Incisive Nerve

The exact anatomy of the incisive nerve has been controversial in the literature. The incisive canal is mostly described as a prolongation of the mandibular canal anterior to the mental foramen. Some studies neglect the presence of a true incisive nerve but rather describe an incisive plexus of nerves supplying the lower teeth.[22-24] Current research seems to confirm the existence of a true incisive nerve as a continuation of the IAN. The exception may be in the central incisor region where a true neurovascular bundle may be lost and nerve bundles become more loosely arranged forming a plexus.[6]

The reported prevalence of the incisive nerve varies based on the study and its methodology. Cadaver dissection and various radiographic techniques have been used to determine the occurrence of the incisive nerve. Cadaver studies report the prevalence as either very high, with multiple reports of 100% prevalence, or very low.[26,28] When a low prevalence has been found, the nerve is described as being ill-defined or as existing mainly as an incisive plexus.[22,24] The ability to detect the presence of the incisive canal from conventional radiographs is limited. Such images often fail to show an incisive canal and is detected in only 11-15% of panoramic radiographs.[25,27] Recent advances in imaging technology have increased the availability of cross-sectional imaging. Jacobs et al. demonstrated the presence of the incisive canal in 93% of spiral CT scans.[27] CBCT has identified the incisive canal in 83% of images.[21,25] Magnetic resonance imaging (MRI) has been recommended as an effective tool for assessing soft tissue structures including the incisive nerve. Krasny et al. observed the incisive canal in 92-99% of MRI images.[9]

As the incisive canal continues anteriorly from its origin, it divides into fine canals known as nutrient canals, which contain the terminal fine braches of nerves and blood vessels.[21] Most nutrient canals of canines and lateral incisors can be detected with MRI. Differentiation between the incisive canal and the nutrient canal is difficult below the central incisor because of the location of the incisive canal.[9] In addition to nutrient canals, the incisive nerve also gives off multiple branches near the midline forming anastomosies with the contralateral incisive nerve. Wadu et al. described anastomosis of the incisive nerves as they crossed the midline and contributed to the innervation of the opposite side.[29] 70% of patients have been shown to have anastomoses at the mental symphysis with 26% of these being plexus-like.[9] This finding is supported by clinical experience in anesthesia, as one-sided anesthesia sometimes fails to numb the area of the incisors.

The incisive canal is always located below the anterior teeth, not beside them as can be seen with posterior teeth and the IAN.[9] The canal has a constant distance from the mandibular border, from its origin to its termination, and is in close proximity to the buccal plate throughout its course.[25] As the canal progresses from its origin mesially, the diameter of the canal becomes significantly narrower until at the level of the central incisors where a single well-defined canal can no longer be detected.[26,27]

Age, gender, and dental status seem to have no effect on the location or size of the incisive nerve. Uchida reported there was no statistical difference in the diameter of the canal in relation to right or left side, gender, dental status, or age.[26] Jacobs found no statistical difference of the effect of age or gender on the location or dimension of the incisive canal.[27] The only statistical difference that has been found to be affected by gender is the distance between the incisive canal and the inferior border of the mandible with the distance being shorter in females.[25]

Lingual Foramina

The lingual foramen is a common finding located at the midline of the lingual mandible at the level of, or superior to, the mental spines.[6] There are often multiple foramina collectively termed lingual foramina. Despite their high prevalence, most anatomy textbooks fail to accurately describe their existence and contents.[6,30] They have been reported in 89-98% of mandibles.[31,32] The contents of the foramina have been a matter of debate. Studies have variously reported the contents as being branches of the sublingual artery, neurovascular branches from the mylohyoid, or branches of both the sublingual artery and mylohyoid nerve.[6,30]

The location and size of the foramina are variable. Choi et al. used micro-computed tomography and found 20% of Korean mandibles had a single foramen, 40% had two foramina, 25% had three foramina, and 15% had four lingual foramina. They also noted that 50% had lateral foramina.[30] Choi's results are similar to a study by Sheikhi that utilized cone beam computed tomography and identified one foramen in 25%, two in 53%, three in 19%, and four foramina in 3% of Iranian patients.[33] Knowledge of these foramina is important for pre-surgical planning of implants in order to avoid complications from damage of the foramina, their canals, or their contents.[30]

Neurosensory Impairment of the Anterior Mandible

Neurosensory impairment is a potential concern associated with dental procedures. 73% of dentists have had a patient experience paresthesia, dysesthesia, or anesthesia postoperatively.[34] The most frequently affected branch is the IAN followed by the lingual nerve.[35] Nerve injury is most frequently caused by extraction of a mandibular third molar but has also been reported with implants and mandibular apical surgeries.[27,36] To aid clinicians in preventing neurosensory complications, many studies have reported measurements of the inferior alveolar canal, mental foramen, anterior loop, incisive canal and lingual foramen.[21] Focus has been primarily on the posterior mandible as injury to the IAN or mental foramen has a high incidence of neurosensory disturbance.[21]

Traditionally, the anterior mandible has been considered an area of minimal surgical risk. Little consideration, if any, is given to the incisive nerve when placing implants in the anterior mandible; however, some authors have reported evidence of discomfort, pain, and disturbances of sensation after placing implants in this area.[5,21,26,38] Data on sensory disturbances after implant placement is mostly based on retrospective studies with only a few prospective studies available.[6] Ellies et al. reported 39% of patients who had implants placed anterior to the mental foramen reported altered sensation with 12% experiencing long-term changes.[38] These results have been confirmed by Abarca and colleagues who found that 33% of their subjects reported neurosensory disturbances after implant placement in the anterior mandible.[5] Bartling et al. described an altered sensation in 5.2% of patients with anterior implants and in 11.8% of patients with implants placed both anterior and posterior to the mental foramen.[39] Walton's prospective study found that 24% of subjects reported altered sensation after implant placement in the anterior mandible, but found the problem was mostly transient with only 1% experiencing persistent sensation changes 1 year after surgery.[40] To minimize this risk, clinicians should utilize proper preoperative planning with cross-sectional imaging for procedures in the symphyseal region.

Cone Beam Computed Tomography

A thorough history, clinical exam and quality radiographs are essential for preoperative diagnosis of teeth undergoing dentoalveolar surgery.[16] Evaluation of the preoperative radiograph is essential to visualize anatomic structures prior to surgery.[21] Historically, conventional periapical and panoramic images have been used for preoperative evaluation of potential endodontic and implant surgery patients. Although these images are fairly accurate in the mesial-distal plane, they lack information regarding the buccal-lingual dimension and superimpose anatomic structures.[41,42] Until recently, this meant the surgeon had to make a three-dimensional decision on the basis of a two-dimensional image. Limitations in conventional radiography have made cross-sectional imaging techniques the radiographic method of choice for pre-surgical evaluation.[21]

Options for cross-sectional imaging in the dental field were limited primarily to medical computed tomography (CT) until the year 2000 when the Food and Drug Administration first approved cone-beam volumetric tomography.[43] While cone beam computed tomography, or cone beam volumetric tomography, has existed since the 1980s, it only recently became a viable option in dentistry.[41,44] The introduction of CBCT represented an important development in dentomaxillofacial radiology and facilitated a shift from two- to three-dimensional visualization.[16]

Cone-beam technology applies a cone-shaped beam of radiation to acquire a cubic volume in a single 360-degree pass, similar to panoramic radiography.[42,43] The volume is made up of voxels, similar to how a digital image is made up of pixels. The data is captured as a volume producing isotropic voxels which allow for accurate measurements to be made in multiple planes. The accuracy of visualizing structures is limited by the voxel size, which ranges from 0.125mm to 0.5mm.[41]

Conventional medical CT, developed in the late 1960s, has been used in dentistry for limited applications.[7] Its high radiation doses and lengthy scanning makes it impractical for most dental applications.[42] Medical CT scanners acquire data by taking multiple slices of a patient simultaneously, then stacking the data and reformatting it to obtain three-dimensional images.[7] These images require multiple passes whereas a CBCT acquires all information in a single pass. Unlike CBCT, voxels produced by CT are anisotropic and therefore measurements are not as accurate.[45] CBCT offers several advantages over medical CT including increased accuracy, higher resolution, reduced scan-time, reduced cost for the patient and the most important advantage of less radiation administered to the patient.[16,46,47] Imaging with CBCT results in an effective absorbed dose ranging from 29.62-510.57μSv, depending on the field of view, as compared to 768.88μSv for CT scans.[61] The Next Generation i-CAT® on landscape mode has an effective absorbed dose of 87μSv with a scan time of 8.9 seconds and reconstruction of the image in 30 seconds. The image has a resolution of 14 bits per voxel with voxel sizes ranging from 0.125mm to 0.4mm based on user selection.[48,49]

CBCT has many advantages over conventional periapical and panoramic studies which have been the standard for preoperative evaluation for apical surgery. The limitations of these techniques include lack of buccal-lingual information, superimposition of anatomic structures such as the cortical plates or other background structures, and inherent magnification and distortion.[41,42] CBCT technology provides the clinician with the ability to observe an area in three different planes, which not only provides information in the buccal-lingual dimension but also eliminates misinterpretation that is often caused by superimposed structures. The uniform magnification and high contrast images produced by CBCTs have been shown to be more accurate in measurements of head and neck structures than conventional radiographs.[25,41] In pre-surgical endodontic planning, CBCT technology is preferred as it allows for assessment of the position of the roots within the bone and proximity of vital structures.[42] CBCT has been shown to have better detection of periapical lesions, missed canals, and vertical root fractures. Any of these factors may preclude a planned apical surgery and allow for more appropriate treatment to be rendered.[50-52] The advantages of CBCT make it the radiographic examination of choice when treatment planning for implant placement. The 2012 position statement from the American Academy of Oral and Maxillofacial Radiology states that the radiographic examination of any potential implant site should include cross-sectional imaging orthogonal to the site of interest and CBCT should be considered the imaging modality of choice.[53]

Despite the many advantages cone-beam technology offers to dentistry, there are several disadvantages associated with CBCTs including limited availability, expense, higher doses of radiation compared to conventional radiography, and scatter from metallic objects.[25] CBCT is primarily limited to major metropolitan areas, but is becoming more widespread as it gains popularity. The expense to purchase a CBCT is cost-prohibitive for many clinicians. Machines range in price from $150,000-$400,000. To evade this cost, dentists may send patients to an imaging center for the CBCT scan and have it read by a dental radiologist.[42] CBCT reduces the radiation exposure compared to medical CT, but exposes the patient to two to eight times more radiation than a panoramic radiograph.[54] The amount of radiation per scan varies by manufacturer, scan time, radiation source, voxel size, field of view, tube voltage and tube current.[41]

OBJECTIVES

The objectives of this retrospective study were to 1) determine the prevalence and course of the incisive canal with respect to the anterior root apices and the mandible, 2) acquire normative information regarding the location of the anterior roots in relation to the mandible, 3) evaluate the anterior mandibular height and width and 4) determine whether gender or age correlated with any of the measurements.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board at the University of Minnesota with number 1301M26223. 106 CBCT scans were taken from 2012 to 2013 using the Next Generation i-CAT® (Imaging Sciences, Hatfield, PA). The scans were taken at the University of Minnesota in Oral and Maxillofacial Radiology of patients of record or referrals from outside clinics. CBCT scans were obtained from a database pool of images taken for diagnostic or pre-surgical assessment unrelated to this study. Eight scans had a field of view (FOV) of 170mm, 62 had a FOV of 130mm and 36 had a FOV of 60mm. The resolution ranged from 0.2-0.3mm. Exclusion criteria included more than one mandibular posterior tooth missing per side excluding 3rd molars, more than one mandibular anterior tooth missing, significant periodontal involvement, resorption of any anterior mandibular tooth, and artifacts of any kind affecting identification of anatomic structures.

Three examiners, two graduate endodontic residents and one dental student, were calibrated for radiographic interpretation of the scans. Examiners viewed the scans on a Dell 24-inch non-glossy monitor with a Dell Optiplex 9010 WorkStation (Dell Inc, Round Rock, TX). The i-CAT Imaging System Software (i-CAT, Imaging Software Sciences International Inc., Hatfield, PA) was used in this study. The software allowed recording of linear measurements of images. Each examiner had the liberty to magnify and change density, contrast, and sharpness to aid in the identification of structures. The examiners viewed cross-sectional slices with a thickness of either 0.2mm, 0.25mm, or 0.3mm. All measurements were made from cross-sectional slices at the radiographic apex of each mandibular anterior tooth present.

For each tooth, a three millimeter line was drawn from the radiographic apex coronally along the long axis of the tooth (red line in Figure 1). Due to limitations in the software-measuring tool, a line exactly 3.0mm could not always be drawn. The closest measurement to 3.0mm was accepted and ranged from 2.93-3.09mm. A line perpendicular to the first measurement was drawn from the outer buccal cortex to the root, from the buccal aspect to the lingual aspect of the root, and from the root to the outer lingual cortex (blue, green, and yellow lines respectively in Figure 1). A protractor was used to verify the line was drawn as close to 90° as possible.

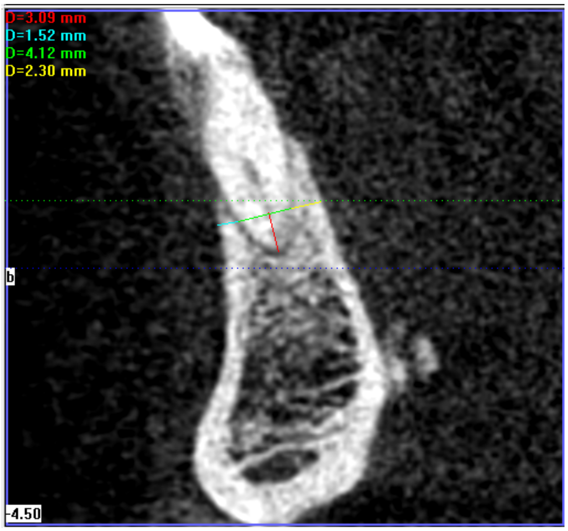


Figure 1.

Images were evaluated for the presence of the incisive canal. To identify the incisive canal, the mental foramen was located and the incisive traced from its origin. If the incisive canal could not clearly be identified, it was recorded as not present. The distance between the incisive canal and the buccal and lingual cortical plates and the diameter of the canal were measured (red, green, and blue lines respectively in Figure 2). Measurements were taken parallel to the Frankfurt horizontal line (green dotted line).

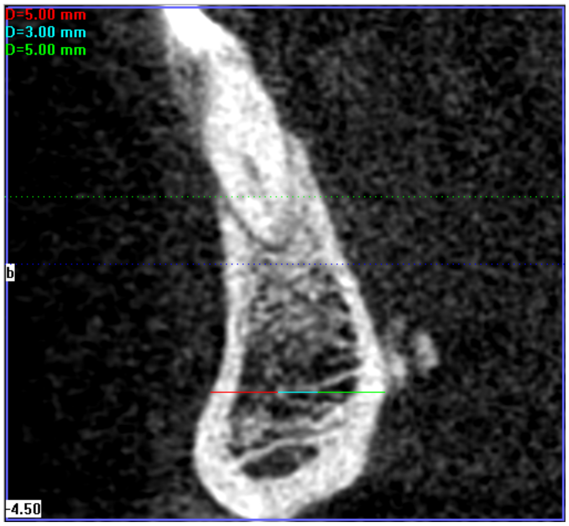


Figure 2.

The relationship of the tooth apex to the incisive canal was determined in both vertical and horizontal dimensions. A vertical line was drawn from the radiographic apex to the superior border of the outer cortex of the incisive canal. The shortest distance to the canal was measured (Figure 3).

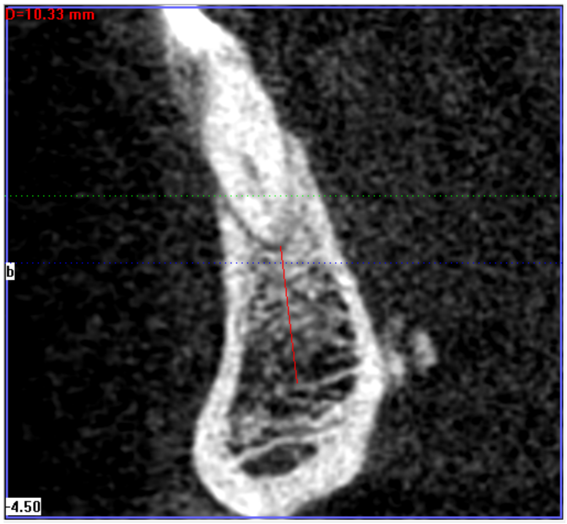


Figure 3.

The horizontal dimension was determined by drawing a vertical line perpendicular to the Frankfurt horizontal line from the tooth apex to the height of the center of the canal (red line in Figure 4). A second line was drawn perpendicular from this point to the center of the canal. The latter measurement was recorded (blue line in Figure 4).

.

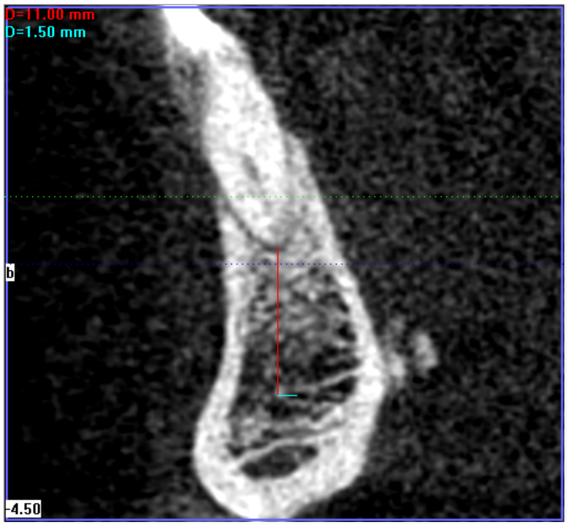


Figure 4.

The height of the mandible was measured from the most inferior portion of the mandible to the alveolar crest (red line in Figure 5). The distance was measured from the alveolar crest to the superior border of the incisive canal (blue line in Figure 5).

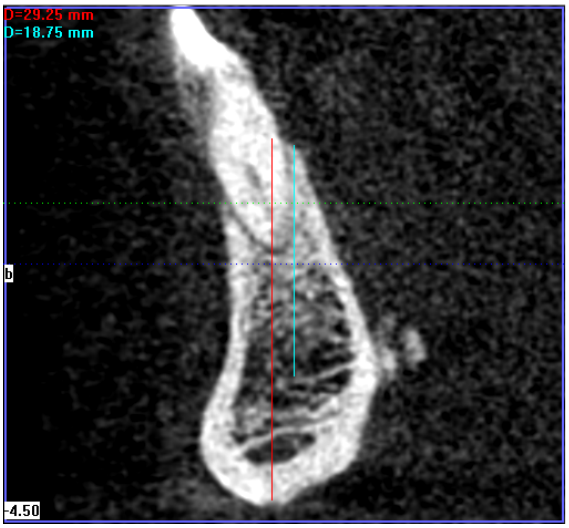


Figure 5.

STATISTICAL ANALYSIS

The data were recorded using Microsoft Office Excel 2010 and statistically analyzed. Means and standard deviations were calculated for each measurement within each exam. Generalized estimating equations were used to compare measurements. Statistical significance was determined at $p \leq 0.05$. If the test for the overall tooth effect was $p \leq 0.05$, then pairwise comparisons were made. P values were adjusted for multiple comparisons using the Tukey method. Pearson correlation coefficients were calculated to compare the change in measurements with gender and age. Statistical analysis was performed with SAS software version 9.3 (SAS Institute Cary, NC).

RESULTS

A total of 106 CBCT scans were studied. The population consisted of 72 females (68%) and 34 males (32%). The mean age was 39.4±16.0 years with a range of 12-69 years old at the time of the scan. A total of 635 teeth were examined in this study. Only one tooth, a left canine, could not be evaluated as it was impacted.

In 80.6% of the images, it was possible to identify the incisive canal. The presence of the incisive canal from the images of the individual teeth is shown in Table 1 and graphically represented in Figure 6. Its prevalence decreased as it moved closer to the midline with the highest percentage being seen in the canines and the lowest in the central incisors. The difference between the canines and central incisors was statistically significant with no difference found between the lateral incisors and either the central incisors or the canines.

TABLE 1. Presence of the incisive canal per tooth area

Tooth	Total (%)
22	94/105 (90%)
23	84/106 (79%)
24	77/106 (73%)
25	78/106 (74%)
26	83/106 (78%)
27	96/106 (91%)

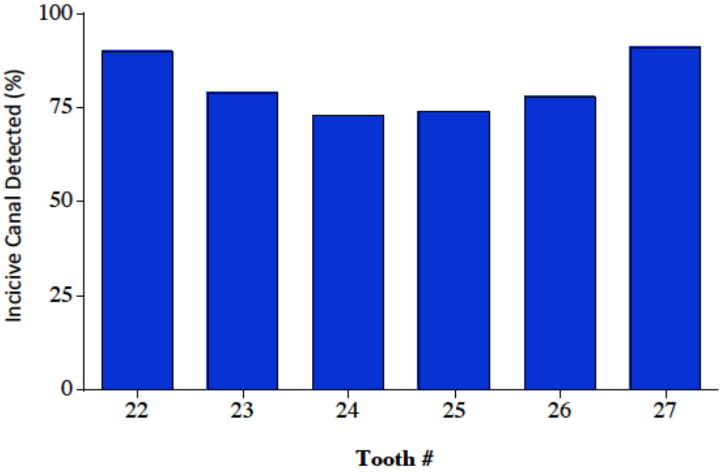


Figure 6.

In 98% of patients, the incisive canal could be identified in cross-sectional images of at least one tooth (Table 2). Two percent of the population did not have an identifiable incisive canal at any point bilaterally. Three percent had a unilateral presentation where the incisive canal could not be identified on one side but was detected in at least one image on the contra-lateral side. The incisive canal could be identified in five of the six cross-sectional images for 13% of patients. The most common image that lacked the canal was the lateral incisor, either tooth 23 or 26. The incisive canal could not be located in two images in 15% of the population and nearly half of these images were from both central incisors. When the incisive canal could not be identified in three cross-sectional images (7%), the centrals plus one of the lateral incisors was the most common combination that lacked the canal. Six percent of patients had four images where the canal could not be identified. The central and lateral incisors were the most common combination of images where it was undetectable. In 4% of patients, the incisive canal could not be identified in more than one image. Typically, one of the canine images contained the canal while the remaining canine and incisors did not.

TABLE 2. Number of teeth per patient with an identifiable incisive canal (I.C.)

Number of teeth	Total (%)	Teeth most often with unidentified I.C.
6	57/106 (54%)	N/A
5	14/106 (13%)	23 or 26
4	16/106 (15%)	24 & 25
3	6/106 (7%)	24 & 25 and either 23 or 26
2	7/106 (6%)	23,24,25,26
1	4/106 (4%)	All anteriors except one canine (#22 or #27)
0	2/106 (2%)	N/A

The measurements taken 3mm coronal to the apex (as seen in Figure 1), are displayed in Table 3. The more anterior the tooth was located within the arch, the smaller the distance from the buccal cortex to the root (Figure 7). Statistical differences were seen among canines, lateral incisors, and central incisors with the exception of between the canines and tooth 26. The mean distance from the lingual plate to the root decreased from canines to lateral incisors to central incisors. There was a statistical difference between all three tooth types. The canines demonstrated the greatest root width followed by the lateral incisors, and finally the central incisors (Figure 8). The difference was significant between the canines and the incisors with the exception of tooth 26. Both canines had no significant difference from tooth 26.

TABLE 3. Measured distances 3mm from the apex (mm)

Tooth #		Buccal plate -root	Lingual plate -root	Root width
22	Min	0.20	0.90	2.60
	Max	5.00	7.43	6.20
	Mean	2.15	3.18	4.34
23	Min	0.00	0.50	2.60
	Max	4.30	6.88	5.50
	Mean	1.66	2.28	4.10
24	Min	0.00	0.25	2.69
	Max	6.08	4.37	6.27
	Mean	1.53	1.65	4.04
25	Min	0.00	0.30	2.53
	Max	4.22	4.81	5.49
	Mean	1.48	1.70	4.07
26	Min	0.20	0.42	2.79
	Max	4.37	4.49	6.66
	Mean	1.58	2.10	4.21
27	Min	0.20	0.79	2.97
	Max	7.60	6.96	6.26
	Mean	2.22	3.09	4.35

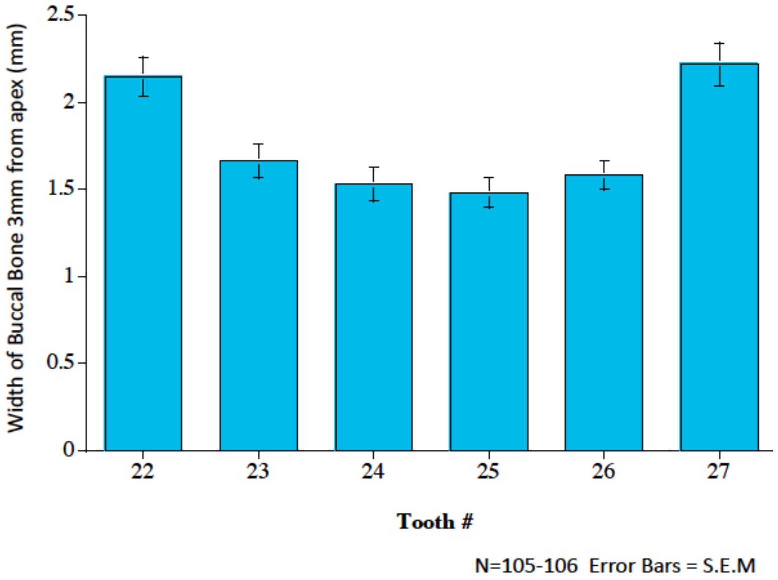


Figure 7.

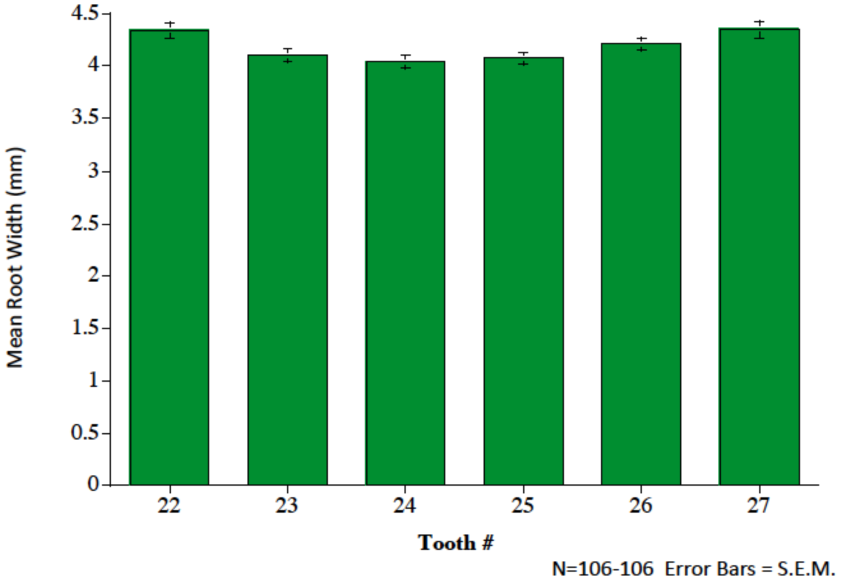


Figure 8.

Measurements taken from Figure 2, at the height of the incisive canal, are displayed in Table 4. The mean thickness of the buccal bone over the canal increased from the canines to the incisors. Statistical differences were seen among canines, lateral incisors, and central incisors, with the exception of a difference between the canines and tooth 26.

The bone lingual to the canal decreased from the canines to the centrals, but the difference was not significant. No trend or statistical differences were noted with regard to the diameter of the incisive canal (Figure 9).

TABLE 4. Measured distances at the incisive canal (mm)

Tooth #		Buccal plate-canal	Lingual plate-canal	Incisive canal diameter
22	**Min**	1.00	2.60	0.90
	Max	8.20	6.20	4.00
	Mean	3.80	4.34	2.29
23	**Min**	1.00	2.60	1.20
	Max	8.75	5.50	4.20
	Mean	4.32	4.10	2.22
24	**Min**	1.75	2.69	1.00
	Max	10.00	6.27	3.50
	Mean	5.10	4.04	2.27
25	**Min**	1.75	2.53	1.25
	Max	9.60	5.49	4.20
	Mean	4.80	4.07	2.38
26	**Min**	1.00	2.79	1.20
	Max	9.40	6.66	3.40
	Mean	4.27	4.21	2.19
27	**Min**	1.00	2.97	1.25
	Max	7.50	6.26	3.80
	Mean	3.75	4.35	2.35

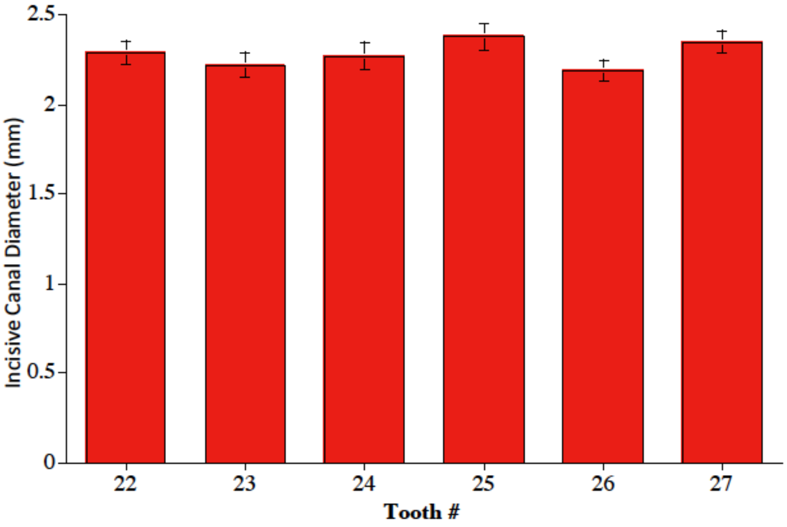


Figure 9

N=75-96/group Error Bars = S.E.M.

The distance from the radiographic apex to the superior border of the incisive canal increased from the canines to central incisors with the difference being statistically different between all tooth types (Table 5 and Figure 10).

TABLE 5. Vertical distance from the root apex to the incisive canal (mm)

Tooth #		Vertical
22	**Min**	0.00
	Max	11.03
	Mean	4.34
23	**Min**	0.90
	Max	15.21
	Mean	6.53
24	**Min**	0.90
	Max	14.00
	Mean	7.14
25	**Min**	0.00
	Max	14.52
	Mean	7.16
26	**Min**	0.75
	Max	13.98
	Mean	6.30
27	**Min**	0.00
	Max	10.80
	Mean	4.59

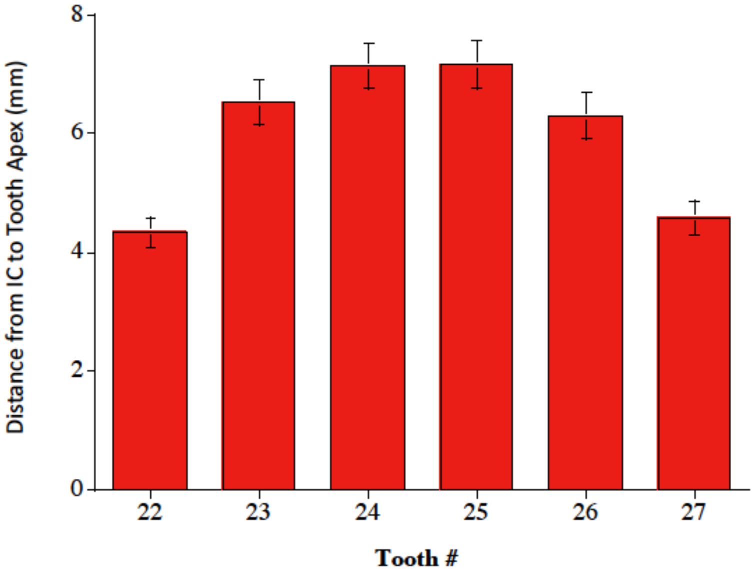


Figure 10. N=77-96 Error bars = S.E.M.

The mean horizontal distance from the tooth apex to the incisive canal is seen in Table 6. The mean for all canals was to the lingual of the apices. From the canines to the centrals, there was a trend for the incisive canal to be located at a greater distance to the lingual of the apex and this difference was significant between the canines and the centrals. On the left side only, there was a significant difference between the central and lateral incisor, whereas no such difference was present on the right side. The canal was found most often to the lingual of the apex in the central incisor images followed by the lateral incisors, and lastly the canines (Table 7 and Figure 11). It was found to the buccal of the apex most often with the canines, followed by the lateral incisors and then the central incisors. There was no trend noted among the teeth when it was located directly below the apex. On the left side, it was most often directly below the central incisor whereas on the right side it was most often below the lateral incisor. No general trends could be noted with regard to the course of the nerve in relation to the root apices as it moved anteriorly through the jaw: 35% had the incisive canal located mostly to the lingual of the roots, 15% were mostly to the buccal, 6% started buccally and moved lingual towards the midline, and 44% had no identifiable trend.

TABLE 6. Horizontal distance from the root apex to the incisive canal (mm)

	22	23	24	25	26	27
Mean	L 0.45	L 0.63	L 1.30	L 1.14	L 0.74	L 0.29
Max buccal	3.50	4.75	6.75	4.60	3.40	4.50
Max lingual	6.00	8.00	7.00	7.40	5.00	5.00

TABLE 7. Relationship of the incisive canal to the root apex

Tooth	% Lingual	% Buccal	% Below
22	57.4%	37.2%	5.4%
23	56.0%	36.9%	7.1%
24	72.7%	19.5%	7.8%
25	71.8%	24.4%	3.8%
26	60.2%	31.3%	8.5%
27	54.2%	38.5%	6.3%

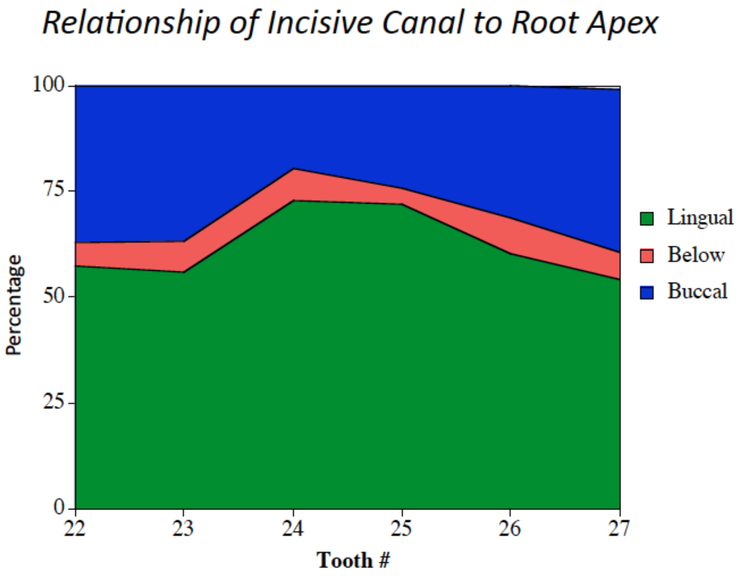
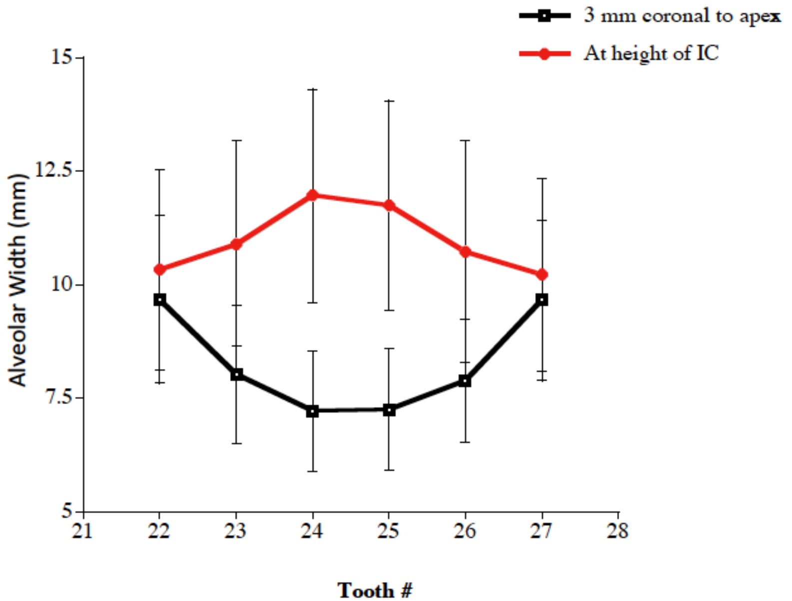


Figure 11.

The mean mandibular width 3mm coronal to the apex and at the incisive canal are given in Table 8 and shown in Figure 12. The mean thickness 3mm coronal to the apex, decreased from canines to central incisors with the difference being significant among all tooth types. The trend was opposite at the level of the incisive canal with the width increasing from the canines to the central incisors. The difference was statistically significant among canines, lateral incisors, and central incisors, with the exception of the canines with tooth 26.

TABLE 8. Mean mandibular width (mm)

	#22	**#23**	**#24**	**#25**	**#26**	**#27**
3mm coronal to apex	9.67	8.03	7.22	7.25	7.9	9.66
Level of incisive canal	10.33	10.9	11.96	11.75	10.72	10.21



N=104-106 apex group; 75-96 IC group
Error Bars = S.D.

Figure 12.

The mean distances from the alveolar crest to the incisive canal and the inferior border of the mandible are shown in Table 9. A decrease from the canine to the central incisor was seen from the alveolar crest to the incisive canal with the exception of tooth 26. None of the differences were statistically significant. The mean distance from the alveolar crest to the inferior border of the mandible was greatest in the central incisor, followed by the lateral incisor and the canine on the left side. On the right side, the central incisor had the greatest distance followed by the canine and finally the incisor. The difference between the laterals incisors on the contralateral sides was significant. All other differences were not significant.

TABLE 9. Vertical dimensions from the alveolar crest (mm)

	#22	#23	#24	#25	#26	#27
To the incisive canal	18.97	18.48	18.33	18.21	17.99	18.80
To inferior border of mandible	28.48	28.80	28.98	28.55	28.09	28.22

There was a statistically significant difference in the distance from the inferior border of the mandible to the alveolar crest between males and females at all locations with the exception of tooth #26. The distances at all other teeth were found to be shorter in females than males. No statistical differences were present in any of the other measurements taken in the study with regard to gender or age. No differences were noted in any of the measurements between left and right sides other than the alveolar crest to inferior border of the mandible in the lateral incisors.

DISCUSSION

The purpose of this study was to provide normative data of structures in the anterior mandible that would be beneficial to clinicians when performing apical or implant surgery, and to evaluate any differences with regard to age or gender. Cone-beam tomography was chosen as the method of evaluation given its ability to evaluate multiple planes, its frequent use in pre-surgical treatment planning, its accuracy in anatomic measurements[41,55] and its accessibility through the University of Minnesota's Oral and Maxillofacial Radiology department.

The presence of a true incisive canal has varied among studies. The present study confirmed the existence of the incisive canal in 80.6% of the cross-sectional images and in at least one image in 95% of patients bilaterally. The presence of the incisive canal located in this study compares well to previous reports. Mraiwa et al. macroscopically observed incisive canals in 96% of cadaver mandibles.[56] CBCT has been reported to identify the incisive canal in 83% of scans by both Parnia et al. using the Promax 3D[21], and Pires et al. utilizing the i-CAT.[25] The incisive canal has been described as appearing as a round radiolucent area surrounded by a radiopaque border.[25,27] During this study, all three examiners experienced difficulty locating the canal due to increased meduallary spaces in the anterior mandible, the small size of the canal which could be confused with meduallary spaces, and a poorly defined radiopaque border. Jacobs evaluated visibility of the incisive and found only 22% had good visibility with 48% having moderate visibility, and 24% having poor visibility. The visibility of the incisive canal is lower than that of the mandibular canal or mental foramen.[27] For these reasons, the examiners in this study viewed the incisive canal from its origin at the mental foramen through the anterior mandible with measurements being made at the radiographic apices of the anterior teeth. If the examiner was unsure of its presence, the canal was recorded as not present.

The incisive canal was located significantly more in the cross-sectional images of the canines than those of the central incisors. When the incisive could not be identified in two or three of the cross sectional images, it was most frequently missing in the images of the central incisors or the central incisors plus a lateral incisor respectively. Mraiwa et al. observed a canal at the midline in only 18% of mandibles with all other cases terminating apically of the lateral incisor, or occasionally the central incisor.[56] The present study provides additional evidence that the incisive nerve loses its morphology as a true neurovascular bundle near the midline and forms a neurovascular plexus. Pires et al. argues that the reason the canal cannot be identified near the midline is because the canal is too small to be visualized on the CBCT. The inability to identify the incisive canal with CBCT near the midline is probably a combination of its small size and branching near the central incisors.

Pires et al. has reported that the incisive canal is present in 64% of patients bilaterally and in 19% unilaterally.[25] The present investigation found a much higher percentage. Only

2% of patients did not have a detectable canal at any point bilaterally and 3% had a unilateral presentation. Pires et al. does not describe the location of the cross-sectional slices that were used to evaluate the presence of the canal.[25] It is possible that the images evaluated were at the origin of the canal and if no canal could be identified at that location it was regarded as not present. In contrast, the present study evaluated the presence of the incisive canal at each tooth regardless if it was located at the origin or in adjacent images. It was observed that at some locations the definition of the canal was lost, but would reappear at a point latter along its course. Interestingly, 54% of patients in this study had the incisive canal identified along all six teeth which compares more closely to Pires' reported 64% bilateral presence.

The average horizontal bone dimensions are important measurements to know during apical surgery. Measurements were taken from a line three millimeters from the radiographic apex along the long axis of the tooth as this represents an ideal resection level. The clinician ideally creates the osteotomy perpendicular to the long axis of the tooth to ensure a 0^{o} bevel. Therefore, the bone and root thickness measurements were made perpendicular to the long axis of the tooth. No published studies have reported the thickness of the bone and roots at the level of resection in the anterior mandible.

The more anterior the tooth location in the mandible, the less buccal bone was present over the root. This makes locating the incisor roots during apical surgery seemingly easy; however, the incisors can have as much as 4.22-6.08mm of buccal bone over the root. The distance from the root to the lingual cortex is also shorter as the tooth is located more anteriorly in the mandible. Care must be taken during root-end resection of and removal of granulomatous tissue to avoid perforation into the lingual soft tissues. The central incisors can have as little as 0.25-0.30mm of bone lingual to the root, which could easily be inadvertently penetrated. As expected, the canines demonstrated significantly greater root width than the incisors. It is critical to incorporate the entire root in the resection to completely remove the etiology and provide an environment for healing. The average osteotomy width without regard to the size of the lesion (the mean buccal bone plus the mean root width) would be 6.49-6.57mm for canines, 5.76-5.79mm for lateral incisors and 5.55-5.57mm for central incisors.

Many studies have been conducted regarding the size of the incisive canal and the thickness of the surrounding bone. The present study found the mean diameter of the canal from the outer cortex ranged from 2.22mm to 2.38mm. Jacobs also measured from the outer cortex of the canal and reported a higher mean diameter of 3.7mm; however, those measurements began distal to the mental foramen whereas the current study did not begin measurements until the level of the canines. Some studies have reported on the inner diameter, not including the surrounding cortication, with results ranging from a mean of 1.1mm[27] to 1.8mm.[56] Incisive canals with large diameters may result in the failed osseointegration of implants because of decreased bone-implant contact. An implant can fail to integrate with a gap of 2mm, which is smaller than the mean diameter of the incisive canal at every point measured.[58] Rosenquist found that the incisive nerve causes implant failure by migration of soft tissue around the implant thereby preventing its osseotintegraion.[58]

The current investigation found no statistical difference with regard to the diameter of the incisive canal and its location in the mandible. Others have reported a change in diameter, with the canal becoming smaller as it progresses toward the midline.[21] Mraiwa et al. reported the canal as largest at its origin, close to the mental foramen, and narrower as it coursed anteriorly. Their statistical analysis revealed a significant but weak correlation between the diameter and the location in the mandible.[56] Uchida et al. found the canal diameter to be 3.1mm at its origin and 1.8mm five millimeters mesial to its origin. The present study may have different results from these previous findings as the canal was measured beginning at the canine rather than its origin. The origin of the incisive canal is the mental foramen, which is typically found mesially and below the apex of the second premolar.[57] It is possible that the greatest change in diameter is seen distal to the canine which may explain why no difference was found in this study.

The mean thickness of the buccal bone over the canal significantly increased from the canines to the incisors ranging from 3.8mm at the canines to 5.10mm at the central incisors and compared well with a previous report of a mean buccal thickness of 3.48mm.[21] Similar to the present study, Pires et al. found that the average buccal bone over the canal increased anteriorly with a mean measurement of 2.2mm at the origin of the canal and 3.3mm at its termination. Pires et al. failed to mention if this difference was statistically significant. Their overall measurements were smaller than those of the current study which may result from their measurements starting at the canal's origin at the mental foramen which is located within the buccal cortex.

The bone lingual to the canal decreased from the canines to the central incisors and ranged from 4.35mm at the canines to 4.04mm at the central incisors which is similar to other studies with reported mean thicknesses of 4.46mm to 5.2mm.[21,25] Pires et al. states that the course of the incisive canal is in close proximity to the buccal plate independent of its location within the mandible. In contrast, this study showed the incisive courses from the buccal towards the lingual as it moves anteriorly.

The distance from the apex of the tooth to the superior border of the incisive canal increased from the canines to central incisors. Two right canines, two left canines and a right central incisor were found to be in direct contact with the canal. Pires et al. evaluated the apex to canal distance at the canal's origin and its terminal end and found it increased from a mean of 4.6mm to 6.1mm respectively. It should be noted that although the distance from the incisors to the incisive canal was greater than that of the canines, it does not indicate an inferior movement in the course of the nerve. The canine teeth are longer than incisor teeth resulting in a shorter distance to the canal without changing its superior-inferior position within the mandible. The horizontal relationship of the incisive canal to the root apex has not previously been quantified and the mean distance was lingual for each tooth type. Although the majority of canals were located to the lingual of the root apices, there was no predictable course of individual canals in relation to the roots. In other words, if the incisive canal started on the lingual side of the apex at the canine, there was no strong trend to predict if it would continue lingual to the remaining tooth apices or if it would move buccaly. The relationship of the canal to the mandible appears to be more predictable in nature with this study finding its course to migrate from the buccal to the lingual as it moves anteriorly. The position of the teeth in relation to the mandible is dynamic depending on malocclusion, history of orthodontics, and super-eruption or drifting as a result of loss of opposing or adjacent teeth. Any of these factors may contribute to a change in the relationship of the root apices to the incisive canal thereby creating a less predictable relationship between the two structures.

At some locations the incisive canal could be found in close proximity to the root apex with the vertical distance being as small as 0.00-0.90mm and the horizontal distance being 0.00mm with the canal directly beneath the apex in 4-9% of patients. The close proximity of these two structures demonstrates how implant placement and apical surgery in this area could potentially result in neurosensory disturbances. There are multiple reports of sensory changes after implant placement in the interforaminal area, while no case reports could be found of sensory changes after apical surgery in the same area. When an implant causes neurosensory changes, it is thought to arise from direct damage to the nerve or stretching of the nerve, or from pressure on the nerve from a hematoma.[6] The osteotomoy created for implants is usually about 0.5mm smaller than the actual implant, creating increased compressive stresses on the bone.[59] Theoretically, if the implant is placed in close proximity to the nerve, it could potentially exhibit continued pressure on the nerve resulting neurosensory changes experienced by the patient. In apical surgery, no modifications are made to the bone or surrounding structures that would exert continued pressure in the area post-surgically. In fact, pre-existing pressure within the bone may be relieved with the removal of an expanding apical lesion. During implant surgery, no significant efforts are made to control hemorrhage as this only affects the ease of the surgery, not the outcome. In contrast, apical surgery requires adequate hemostasis prior to placing a root-end filling. Implant surgery may be more likely to produce a hematoma thereby creating another potential avenue for neurosensory impairment. Implants may have a higher potential for neurosensory changes in the anterior mandible than apical surgery. This should be carefully considered by clinicians as dentists are increasingly electing to place implants instead of referring for apical surgery.

The risk of neurosensory disturbances may be reduced by the presence of branching, anastomoses, and cross-innervation of the incisive nerves. The presence of a plexus-like complex near the midline may explain why more neurosensory issues are not seen. This plexus and branching of the incisive nerve, likely allows an area to be innervated by multiple nerve branches. Given that there is a considerable degree of plasticity in the nerve, patients may have damage to neurosensory structures with transient clinical symptoms if the area can still receive sensation from other nerves. When damage to a nerve does occur, sprouts from non-injured nerves may supply some reinnervation.

The examiners noted the presence of a lingual foramen in most patients (Figure 13). Although no quantification was made, several variations of the lingual foramen were noted including variations with two or three lingual foramina/canals (Figure 14). The presence of these canals may be another cause for neurosensory disturbances after implant placement. The lingual canal present in Figure 13 extends three fourths of the thickness of the mandible, nearly reaching the inner aspect of the buccal cortex. Placement of an implant into this region could cause direct damage to the neurovascular bundle carried within the canal, leading to sensory disturbances.

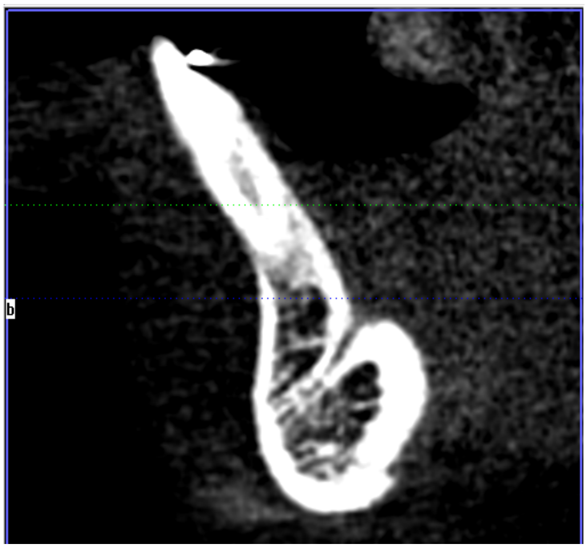


Figure 13.

Figure 14.

The mean mandibular width was measured at two different levels. During apical surgery, the clinician is concerned with the width of the mandible perpendicular to the long axis of the tooth as this is where the osteotomy is created. This is located within the alveolar crest which is narrower than the body of the mandible and becomes thinner near the midline. Implants are not placed in the same bucco-lingual orientation as the teeth. Typically implants are placed more centered in the mandible providing sufficient bone circumferentially for primary stability. In contrast to apical surgery, clinicians performing implant surgery are more concerned with the width of the bone parallel the long axis of the mandible. In the present study, the mean width at the incisive canal ranged from 10.21-11.96mm which compares with measurements reported by Mraiwa et al. of 10.5-11.2mm.[56]

The distance from the alveolar crest to the incisive nerve tended to move inferiorly as it approached the midline, although the difference was not significant. Mraiwa et al. found that the course of the incisive was slightly downward as it coursed towards the midline.[56] This study found the overall course of the incisive canal within the mandible from the canine to the central incisor is in a lingual and slightly inferior direction and found no differences in any of the measurements with regard to age or gender, which has been uniformly established throughout the literature. The only gender difference noted was from the alveolar crest to the inferior border of the mandible. This finding is expected as females have been shown to have a smaller mandibular height than males. The incisive canal is constant between genders relative to the alveolar crest, but varies relative to the inferior border of the mandible with the distance being shorter in females.[25]

A limitation of this study was the interpretation of radiographs. Although CBCT has been shown to accurately measure structures of the head and neck, visualization of the incisive canal can be difficult. The best way to verify the presence of the incisive canal identified with CBCT would be to compare it to histologic findings. The difficulty of designing an in vitro study that evaluates CBCT followed by histologic sectioning, would be obtaining a sufficient number of specimens.

Another critique of this experiment is that each scan was only examined once by one examiner. Although calibration occurred, there were no measures was taken to verify that all three examiners accurately calibrated. Ideally, each scan would be viewed and have measurements taken by two examiners. Inter-rater reliability could then be calculated to confirm accuracy among examiners. There was also no evaluation of intra-rater reliability which could have been evaluated by having the same examiner evaluate each scan twice. Due to the time constraints, the necessary steps to ensure inter- and intra-rater reliability could not be completed.

The data collected in this study were fairly consistent with the occasional exception of tooth 26 which appeared to be an outlier in several of the exams. In the root width measurements, the canines were significantly different from all the incisors with the exception of tooth 26. The amount of bone buccal to the incisive canal had statistical differences among the canines, lateral incisors, and central incisors with the exception of the difference between the canines and tooth 26. The mandibular width at the incisive canal was statistically significant between teeth except the canines and tooth 26. This discrepancy in the data could be from an error in the measurements related to tooth 26.

To verify that the data collected is indeed correct, another observer or the same observer would need to revisit the scans and confirm that the measurements of tooth 26 are correct. Another less likely possibility is that that the sample size was not large enough to detect a statistically significant difference. The original research design of this project included evaluation of 300 scans, with 100 scans completed per examiner. The number of scans evaluated was reduced based on the unanticipated length of time to evaluate the location of the incisive canal in most scans.

CONCLUSIONS

The clinical significance of this study can be realized through mapping of the incisive canal and its proximity relative to anatomic structures during pre-surgical treatment planning. Collectively, the data from this study indicates surgical anatomic relationships should be considered in pre-surgical planning to avoid neurosensory disturbances and other potential complications. With the increased interest in performing a thorough pre-surgical examination in the interforaminal region, cross-sectional images should be utilized to obtain information on the appearance, location, and course of the foramina and canals and their relation to other anatomical structures of the jaw.

BIBLIOGRAPHY

1. de Chevigny C, Tao TT, Basrani BR, Marquis V, Farzaneh M, Abitbol S, Friedman S. Treatment outcomes in endodontics: the toronto study-phase 4: initial treatment. J Endod 2008a;34:258-263.

2. de Chevigny C, Tao TT, Basrani BR, Marquis V, Farzaneh M, Abitbol S, Friedman S. Treatment outcomes in endodontics: the toronto study-Phases 3 and 4: orthograde retreatment. J Endod 2008b;34:131-7.

3. Torabinejad M, McDonald NJ. Endodontic Surgery. In: Torabinejad M, Walton RE, eds. Endodontics: Principles and Practice. 4th ed. St. Louis: Saunders Elsevier., 2009:357

4. Johnson BR, Witherspoon DE. Periradicular surgery. In: Cohen S, Hargreaves KM, eds. Pathways of the pulp. 10th ed. St Louis: Mosby, Inc., 2006:738.

5. Abarca M, van Steenberghe D, Malevez C, De Ridder J, Jacobs R. Neurosensory disturbances after immediate loading of implants in the anterior mandible: an initial questionnaire approach followed by a psychophysical assessment. Clin Oral Invest 2006;10:269-77.

6. Mraiwa N, Jacobs R, van Steenberghe D, Quirynen M. Clinical assessment and surgical implications of anatomic challenges in the anterior mandible. Clin Implant Dent Relat Res 2003;5:219-25.

7. Patel S, Dawood A, Pitt Ford T, Whaites E. The potential applications of cone beam computed tomography in the management of endodontic problems. Int Endod J 2007;40:818-830.

8. Simonton JD, Azevedo B, Schindler WG, Hargreaves KM. Age- and gender-related differences in the position of the inferior alveolar nerve by using cone beam computed tomography. J Endod 2009;35:944-49.

9. Krasny A, Krasny N, Prescher A. Study of inferior dental canal and its contents using high resolution magnetic resonance imaging. Sug Radiol Anat 2012;34:687-93.

10. Gilheany PA, Figdor D, Tyas MJ. Apical dentin permeability and microleakage associated with root end resection and retrograde filling. J Endod 1994 (20):22-26.

11. Kim S, Kratchman S. Modern endodontic surgery concepts and practice: a review. J Endod 2006;32:601-623.

12. Mauger MJ, Schilder WG, Walker WA III: An evaluation of canal morphology at different levels of root resection in mandibular incisors. J Endod 1998 24 607.

13. Gagliani M, Taschieri S, Molinari R. Ultrasonic root-end preparation: influence of cutting angle on the apical seal. J Endod 1998 24:726.

14. Tidmarsh BG, Arrowsmith MG. Dentinal tubules at the root ends of apicected teeth: a scanning electron microscopic study. INt Endod J 1989;22:184 .

15.Sauveur G, Boccara E, Colon P, Sobel M, Boucher Y. A photoelastimetric analysis of stress induced by root-end resection. J Endod 1998 24: 740.

16. Bornstein MM, Lauber R, Sendi P, von Arx T. Comparison of periapical radiography and limited cone-beam computed tomography in mandibular molars for analysis of anatomical landmarks before Apical Surgery. J Endod 2011;37:151-157.

17. Frankle KT, Seibel W, Dumsha TC. An anatomical study of the position of the mesial roots of mandibular molars. J Endod 1990;16:480-5.

18. Bavitz JB, Harn SD, Hansen CA Lang, M. An anatomical study of mental neurovascular bundle-implant relationships. Int J Oral Maxillofac Implants 1993;8:563-567.

19. Escoda-Francoli J, Canalda-Sahli C, Soler A, Figueiredo R, Gay-Escoda C. Inferior alveolar damage because of overextended endodontic material: a problem of sealer cement biocompatibility? J Endod 2007:33;1484-1489.

20. Olivier E. The inferior dental canal and its nerve in the adult. Br Dent J 1928;49:356-358.

21. Parnia F, Moslehifard E, Hafezeqoran A, Mahboub F, Mojaver-Kahnamoui H. Characterisitcs of anatomical landmarks in the mandibular interforaminal region: A cone-beam computed tomography study. Med Oral Patol Oral Cir Bucal 2012;17:420-5.

22. Starkie C, Stewar D. Inra-mandibular course of inferior dental nerve. J Anat 1931;65:319-323.

23. Denissen HW, Velduis HA, van Faassen F. Implant placement in the atrophic mandible: an anatomic study. J Prosthet Dent 1984; 52:260-263.

24. Polland KE, Munro, Reford G, et al. The mandibular canal of the edentulous jaw. Clin Anat 2001; 14445-452.

25. Pires CA, Bissada NF, Becker JJ, Kanawati A, Landers MA. Mandibular incisive canal: cone beam computed tomography. Clin Implant Dent 2012;14:67-73.

26. Uchida Y, Yamashita Y, Goto M, Hanihara H. Measurement of anterior loop length for the mandibular canal and diameter of the mandibular incisive canal to avoid nerve damage when installing endosseous implants in the interforaminal region. J Oral Maxillofac Sug 2007;65:1172-9.

27. Jacobs R, Mraiwa N, vanSteenberghe D, Gijbels F, Quirynen M. Appearance, location, course, and morphology of the mandibular incisive canal: an assessment on spiral CT scan. Dentomaxillofac Radiol 2002;31:322-7.

28.De Andrade E, Otomo-Cogrel J, Pucher J, Ranganath KA St George N Jr. The intraosseous course of the mandibular incisive nerve in the mandibular symphysis. Int J Periodontics Restorative Dent 2001; 21:591-597.

29. Wadu SG, Penhall B, Townsend GC. Morphological variability of the human inferior alveolar nerve. Clin Anat 1997;10:82-87.

30. Choi D, Woo YJ, Won SY, et al. Topography of the lingual foramen using micro-computed tomography for improving safety during implant placement of anterior mandibular region. J Craniofac Surg 2013;24:1403-1407.

31. Shiller WR, Wiswell OB. Lingual foramina of the mandible. Anat Rec 1954;119:387-390.

32. Liang X, Jacobs R, Lambrichts I, et al. Lingual foramina on the mandibular midline revisited: a macroanatomical study. Clin Anat 2007;20:246-251

33. Sheikhi M, Mosavat F, Ahmadi A. Assessing the anatomical variations of lingual foramen and its bony canals with CBCT taken from 102 patients in Isfahan.Dent Res J (Isfahan) 2012;9:45-51.

34. Misch CE, Resnik R. Mandibular nerve neurosensory impairment after dental implant surgery; management and protocol. Implant Dent 2012;19:378-84.

35. Tay ABG, Zuniga JR. Clinical characteristics of trigeminal nerve injury referrals to a university centre. Int J Oral Maxillofac Surg 2007;36:922-927.

36. Palma-Carrio C, Balaguer J, Penarrocha-Oltra D, Penarrocha-Diago M. Irritative and sensory disturbances in oral implantology. Literature review. Med Oral Patol Oral Cir Bucal 2011;16:1043-6.

37. Ioannides C, Borstlap WA. Apicoevtomy on molars: a clinical and radiographical study. Int J Oral Surg 1983;12:73-9.

38. Ellies LG. Altered sensation following mandibular implant surgery: A retrospective study. J Prosthet Dent 1992;68:664-71.

39. Bartling R, Freeman K, Kraut RA. The incidence of altered sensation of the mental nerve after mandibular implant placement. J Oral Maxillofac Surg 1999;57:1408-10.

40. Walton JN. Altered sensastion with implants in the anterior mandible: A prospective study. J Prosthet Dent 2000;83:443-9.

41. Kim TS, Caruso JM, Christensen H, Torabinejad M. A comparison of cone-beam computed tomography and direct measurement in the examination of the mandibular canal and adjacent structures. J Endod 2010;36:1191-4.

42. Cotton TP, Geisler TM, Holden DT, Schwartz SA, Schilder WG. Endodontic applications of cone-beam volumetric tomography. J Endod 2007;33:1121-32.

43. Danforth RA. Cone beam volume tomography: a new digital imaging option for dentistry. J Calif Dent Assoc 2003;31:814-5.

44. Robb RA. Computer-based three-dimensional medical imaging. J Med Syst 1982;6:535-7.

45. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J Can Dent Assoc 2006;72:75-80.

46. Yajima A, Otonari-Yamamoto M, Sano T, Hayakawa Y, Otonari T, Tanabe K, Wakoh M, Yonezu H, Nakagawa K, Yajima Y. Cone beam CT (CB Throne) applied to dentomaxillofacial region. Bull Tokyo Dent Coll 2006;47:133-41

47. Ziegler CM, Woertche R, Brief J, Hassfeld S. Clinical indications for digital volume tomography in oral and maxillofacial surgery. Dentomaxillofac RAd 2002;31:126-30.

48. Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT device and 64-slice CT for oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:106-14.

49. Maillet MA.Cone beam computed tomographic evaluation of maxillary. Masters thesis. University of Minnesota 2008.

50. Low KM, Dula K, Burgin W, et al. Comparison of periapcial radiography and cone-beam tomography in posterior maxillary teeth referred for apical surgery. J Endod 2008;34:557-62.

51. Matherne RP, Angelopoulos C, Kulild JC et al. Use of cone-beam computed tomography to identify root canal systems in vitro. J Endod 2008;34:87-9.

52. Nair MK, Nair UP. Digital and advanced imaging in endodontics: a review. J Endod 2007;33:1-6.

53. Tyndall DA,Price JB, Tetradis S, Ganz SD, Hildebolt C, Scarfe WC. Position statement of the American Academy of Oral and Maxillofacial Radiology on selection criteria for the use of radiology in dental implantology with emphasis on cone beam computed tomography. Oral Surg Oral Med Oral PAthol Oral RAdiol 2012;113:817-826.

54. Okano T, Harata Y, Sugihara Y et Absorbed and effective doses from cone beam volumetric imaging for implant planning. Dentomaxillofac Radiol 2009;38:79-85.

55. Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;103:534-42.

56. Mraiwa N, Jacobs R, Moerman, Lambrichts I, van Steenberghe D, Quirynen M. Presence and course of the incisive canal in human mandibular interforaminal region: two-dimensional imaging versus anatomic observations. Surg Radiol Anat 2003;25:416-423.

57. Phillips JL, Weller RN, Kulild JC. The mental foramen: part 2. Radiographic position in relation to the mandibular second premolar. J Endod 1992;18:271-4.

58. Rosenquist B. IS there an anterior loop of the inferio alveolar nerve? Int J Periodontics Restorative Dent 1996;16:40-45.

59. Greenstein G, Cavallaro J, Tarnow F. Assessing bone’s adaptive capacity around dental implants: A literatire review. J Am Dent Assoc 2013;144:362-68.

60. Holland GR. Experimental trigeminal nerve injury. Crit Rev Oral Biol Med 1996;7:237-58.

61. Okano T, Harata Y, Sugihara Y, Sakaino R, Tsuchida R, Iwai K, Seki K, Aradki K. Absorbed and effective doses from cone beam volumetric imaging for implant planning. Dent Maxillo Rad 2009;38:79-85.