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An Analysis of Anterior Mandibular Anatomy Using Cone Beam Computed Tomography: A Study of Dentate and Edentulous Mandibles

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Tomography: A Study of Dentate and Edentulous Mandibles

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An Analysis of Anterior Mandibular Anatomy Using Cone Beam Computed Tomography:

A Study of Dentate and Edentulous Mandibles

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ABSTRACT

Statement of Problem: The anterior mandible has conventionally been deemed as a relatively

"safe zone" for dental implants due to perceived lack of innervation to the area as well as its

relatively thick cortices and dense bone. However, with the evolution of cone beam computed

tomography (CBCT), a number of anatomic challenges have been identified by clinicians that

can lead to neuropathy and life-threatening hemorrhage if violated. The three critical anatomic

structures in this area that pertain to implant placement are the sublingual artery (SLA),

submental artery (SMA), and the mandibular incisive canal. Currently, there is a lack of

knowledge regarding average measurements of these anatomic structures in relation to a specific

non-variable landmark. Furthermore, it is not known if there are any significant variations of

these anatomic structures in dentate and edentulous patients. While these structures may be

identifiable on a CBCT scan, mandatory CBCTs are not required by practitioners in order to

perform implant surgery in the anterior mandible.

Purpose: To determine if standardized average values can be obtained for the sublingual artery

(SLA), submental artery (SMA), and mandibular incisive canal (MIC), and if differences exist

between dentate and edentulous patients.

Materials and Methods: CBCTs of 125 edentulous and 100 dentate subjects were evaluated at

the anterior mandible for incidence of visualization of the SLA, SMA, and MIC. Measurements

of these three structures were also made from the inferior cortical border of the mandible to the

superior border of each structure in order to gain average anatomical measurements. The cross-

sectional shapes of anterior mandibles were also categorized and prevalence of each shape in this

sample was calculated.

Results: The incidence of visualization of the SLA on CBCT was found to be 100% for edentulous subjects and 98% for dentate subjects. The SLA was located approximately 15mm above the inferior border of the mandible. The incidence of visualization of the SMA on CBCT was 94% for edentulous subjects and 88% for dentate subjects. The SMA was located approximately 5mm above the inferior border of the mandible. The incidence of visualization of the MIC on CBCT was 61% for edentulous subjects and 59% for dentate subjects. The MIC was found to be approximately 1.5mm in diameter at the lateral incisor and canine regions. The MIC was located approximately 11mm above the inferior border of the mandible in edentulous patients, and approximately 14mm above the inferior border of the mandible in dentate patients. The edentulous mandibular ridge attained a buccal-lingual width of 6 mm at a mean distance of 4 mm below the ridge crest in this patient sample. A new classification system for the cross-sectional morphology of the anterior mandible was characterized and includes the following shapes: hourglass, ovoid, pear, sickle, and triangular. The pear was the most commonly visualized cross-sectional morphology among both edentulous and dentate patients.

Conclusions: The sublingual artery and submental artery can be consistently identified in the anterior mandible using CBCT, both in dentate and edentulous patients. The SLA was located approximately 15mm above the inferior border of the mandible and the SMA was located approximately 5mm above the inferior border of the mandible. The mandibular incisive canal was not consistently visualized. The cross-sectional morphology of the anterior mandible is diverse in dentate and edentulous mandibles with pear shape being the most common in both situations. These findings should be taken into consideration when treatment planning for implants using CBCT or panoramic radiography.

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INTRODUCTION

Literature Review

Over the past three decades, dental implants have emerged as a mainstay in the esthetic, functional, and prosthetic rehabilitation of patients with partial and complete edentulism.[1] Dental implants are widely used in a variety of prosthodontic treatments such as single tooth replacement, multiple teeth replacement, support for complete arch fixed dental prostheses, and retention for removable complete and partial overdentures. Historically, dental implants were primarily intended for placement in atrophic edentulous mandibles for metal-resin screw-retained fixed complete dentures.[2] Currently, dental implants in the anterior mandible have become increasingly common due to popular prosthetic treatments such as two-implant retained mandibular overdentures, mandibular fixed implant-supported prostheses, and implant-supported four-to-six-unit anterior fixed dental prostheses on partially edentulous patients. Each of these treatment modalities includes at least two implants in the anterior mandible, typically at the positions of the lateral incisors or canines.

The mandibular anterior region has historically been considered a "safe and predictable zone" for implant surgery.[3,4] The predictability was attributed to the relatively thick cortices and dense bone; however, the "safe zone" concept was a misnomer, primarily due to the lack of knowledge and appreciation of anatomic structures in this region. According to Per-Ingvar Branemark's original protocol, the dental implant placement procedure was to be completed in the surgical operating room in a hospital setting rather than an out-patient setting, as largely performed today.[5] Performing implant surgery in a hospital operating room allowed clinicians to better manage any intra-operative complications, such as arterial bleeding, that were unexpectedly encountered. The same argument holds true for other oral surgical procedures

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performed in the anterior mandible, such as orthognathic surgeries, and oncologic or trauma related resections that are all currently performed in a hospital setting. As an increasing number of clinicians converted from the hospital operating room environment to the outpatient setting in a dental chair environment, numerous reports have emerged recounting adverse outcomes related to implant surgery in the anterior mandible.[6] Recent literature discusses a number of adverse events ranging from neurosensory disturbances to life-threatening complications in this region, including formation of sublingual hematoma, upper airway obstruction, and profuse, pulsatile bleeding.[7] Therefore, thorough knowledge of surgical anatomy of the anterior mandible is critical for many routine dental procedures including dental implant placement, dental extractions, donor site bone harvesting of mandibular symphysis, and torus removal.[8]

There are three significant anatomic structures in the anterior mandible that deem surgery in this region challenging. These include the sublingual artery, the submental artery, and the mandibular incisive canal that houses the incisive neurovascular bundle.[9] The sublingual artery is a terminal branch of the lingual artery. The lingual artery arises from the external carotid artery between the superior thyroid artery inferiorly and the facial artery superiorly. It travels deep to the hypoglossal nerve, the stylohyoid muscle, and posterior belly of the digastric muscle. It then dives deep to the hyoglossus muscle.[10] The sublingual branch arises at the anterior border of the hyoglossus muscle, and courses forward in the anterior floor of the mouth above the mylohyoid muscle to anastomose with the contralateral artery, as well as the submental branch of the facial artery. This anastomosis may result in small alveolar branches which penetrate the lingual cortex of the mandible at the lingual foramen.[10] The sublingual artery provides the major blood supply to the floor of the mouth; its branches perfuse the sublingual salivary gland, the

mylohyoid and surrounding muscles, and the gingiva and mucosa of the mandibular anterior teeth.[9,11,12]

The submental artery is a terminal branch of the facial artery, which originates from the external carotid artery. The facial artery emerges either superior to the lingual artery or in common with it. It passes deep to the stylohyoid and digastric muscles, and loops anteriorly on the inferior border of the mandible to travel a deep groove in the submandibular salivary gland.[10] At this point, the submental branch travels anteriorly on the surface of the mylohyoid muscle and anastomoses with the sublingual branch of the lingual artery and the mylohyoid branch of the inferior alveolar artery.[12] These terminal anastomosing branches may penetrate the lingual cortex via the lingual foramen or may enter via accessory lingual foramina.[13,14] A study by Loukas et al in 2008 found that 27% of human cadavers studied had the sublingual artery arising from the submental artery rather than the lingual artery.[15] Anatomical aberrations such as this may make surgical complications in the anterior mandibular region of atrophic mandibles unpredictable without proper imaging.

A number of authors have described anatomic findings regarding this intricate perfusion of the anterior mandible in cadaver specimens and radiographic studies; however, all of these studies examined limited variables of anatomy. Numerous studies have dissected cadaver specimens to study variable arterial branching patterns, as well as the location of arterial perforation of the mandibular lingual cortical plate.[13,15-17] However, these studies were all completed on human cadavers or dried mandibles. Radiographic studies of the blood supply to the anterior mandible have also been conducted to support cadaver evidence. In a study by Tepper et al in 2001, traditional computed tomography (CT) scans were used to evaluate the presence of sublingual canals, the distance of these canals to the menton, and the intraosseous

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paths of these canals.[18] This study used 70 total scans, but did not describe the dental status

(dentate or edentulous) of the patients.[18] Lustig et al in 2003 also evaluated the sublingual

arterial supply. However, this study employed the use of ultrasound/doppler to evaluate only the

diameter of the sublingual artery and blood flow patterns through this artery.[19] No evaluation of

precise location of bony perforation of this artery was attempted. In 2007, Longoni et al

compared 100 dry skull cadaver mandibles and 100 traditional CTs of mandibles of living

patients to examine location and number of lingual vascular canals in the mandible.[20] This study

was novel in that it examined CTs of living patients; however, the data collected were limited to

the number and diameter of lingual vascular canals and the location of these canals relative to the

dentition. No measurement of superior-inferior location within the mandible was described, nor

were measurements taken of edentulous mandibles, which is of particular interest to the

clinician.[20] Finally, in 2009, Tagaya et al evaluated cadaver sections and 200 traditional CT

scans of living patients.[21] This study determined the number and position of lingual foramina of

the mandible relative to the mental spine and midline.[21] While this study used CT scans of a

large sample of living patients, no absolute measurements were made that would be of

significant clinical use to the practitioner. Despite the wealth of information gained from these

studies, no examination of differences between dentate and edentulous mandibles was

mentioned, nor was any standardized measurement attempted from a non-variable anatomic

structure (such as the inferior border of the mandible) to derive average measurements.

Furthermore, no studies investigated the presence and location of the submental artery. Further

studies using current 3-dimensional CBCT technology are needed in order to provide clinically

applicable data for practicing dentists.

The mandibular incisive canal (MIC) houses the incisive artery, vein, and nerve which perfuse and innervate the anterior mandibular teeth, including the first premolars, canines, and incisors.[10] The incisive artery is a branch of the inferior alveolar artery. The inferior alveolar artery arises from the maxillary artery, a terminal branch of the external carotid artery. The inferior alveolar artery courses inferiorly, giving off the mylohyoid artery before entering the mandibular foramen and travelling through the mandibular canal. In this canal, it divides into two branches.[10] The mental branch exits out through the mental foramen in the area of the premolars to perfuse the chin and lower lip. The incisal branch remains in the mandibular canal anteriorly to the mental foramen and sends perfusing branches to the incisor teeth as well as to the contralateral artery.[12]

The mandibular incisive nerve is the final branch of the inferior alveolar nerve, a branch of the mandibular division of the trigeminal nerve.[12] It enters the lingual aspect of the posterior mandible via the mandibular foramen and travels anteriorly within the mandibular canal. The inferior alveolar nerve traverses the mandible from lingual to buccal, and splits into the mental and incisive nerves in the area of the premolars.[10] The mental nerve emerges from the mental foramen and travels with the mental artery to supply innervation to the skin of the lower lip and chin, and the gingiva and mucosa anterior to the second premolar. The incisive nerve remains in the canal medial to the mental foramen, termed the mandibular incisive canal. The incisive nerve provides innervation to the mandibular anterior teeth, including the first premolars, canines, and incisors.[22,23] However, in a number of cases, the MIC may be indistinct, suggesting that this important neurovascular bundle may simply travel through the medullary spaces of the mandibular trabecular bone.[24]

Numerous studies have examined anatomy of the mandibular incisive canal in cadaver specimens, panoramic radiographs, and computed tomography.[23,25-30] These studies have mostly focused on percent occurrence, estimated diameter of the mandibular incisive canal, and distance from root apices of lateral incisors and canines. Mardinger et al in 2000 and Mraiwa et al in 2003 both examined percent occurrence and diameter of the mandibular incisive canal (MIC) using cadaver specimens only.[25,26] Jacobs et al in 2002 and 2004 also examined occurrence and diameter of the MIC.[27,28] These studies used traditional spiral computed tomography and panoramic radiography respectively. In these studies, the presence of the MIC via panoramic radiography was only present in 15% of patients, and had "good visibility" in only 1%, which is insufficient.[27,28] Uchida et al. in 2007, and again in 2009, evaluated MIC anatomy in cadaver specimens, and cadavers along with CBCT respectively.[29,30] This was the first study of this type to use CBCT, the standard three-dimensional imaging in dental medicine to evaluate anatomy; however, this study only investigated four CBCT scans which were taken of cadavers, not living patients. Finally, Apostolakis et al in 2013, used CBCT of living patients to examine dimensions of the MIC only and determined mean distances of the MIC to apices of adjacent teeth, not an unchanging structure through time.[23] Furthermore, no measurements were noted for edentulous mandibles. Currently, there is a lack of data comparing the anatomy of the MIC in dentate and edentulous patients using conventional three-dimensional CBCT analysis in living patients.

While description of these anatomic structures seems straightforward, individual variation can be vast. This variability may be complicated by the presence or absence of dentition, as degree of alveolar bone atrophy can have a large influence on anatomic variation.[31] In the edentulous mandible, impingement of the MIC during implant surgery is typically not of significant concern for three reasons: 1) sclerosis of the incisive artery with age, 2) hemorrhage

may be controlled by implant placement itself, and 3) absence of mandibular anterior teeth may render the innervation of the incisive nerve inconsequential.[9] However, a number of cases have reported surgical complications in patients with enlarged MIC, including extreme post-operative pain from neural injury and severe pulsatile hemorrhage from implant invasion of the mandibular incisive artery.[8,22] Other complications reported for dentate and edentulous patients include life-threatening vascular injuries. Numerous reports discuss surgical cases involving perforation of the lingual cortex of the mandible resulting in large sublingual hematoma formation causing near-fatal airway obstruction. In all reported cases, the sublingual or submental artery had been lacerated during osteotomy preparation and necessitated emergency hospitalization.[3,32-34]

The current consensus, or the standard of care, for surgical intervention in the anterior mandible does not require the use of three-dimensional imaging. However, the ability of conventional two-dimensional radiographic imaging (panoramic and periapical radiography) to reveal these important structures are severely limited in appreciation of the MIC and incapable of visualization of the sublingual and submental arteries.[26,28] The use of three-dimensional cross-sectional imaging using CBCT has resulted in better visualization of alveolar ridge topography and proximity of vital anatomic structures.[35] However, current guidelines continue to only recommend the use of CBCT on an individual needs basis as an alternative to conventional imaging.[35] Not all cases warrant full CBCT analysis, which potentially increases the cost of treatment as well as radiation exposure to the patient. Therefore, a need for standardized measurements and incidence of visualization of important anatomy using the best clinical visualization practices is needed.

Two additional topics of interest in this study involve the buccal-lingual width of the alveolar crest in the anterior mandible, and the related cross-sectional shape of the anterior

mandibular bone. Rehabilitation of the dentition using dental implants requires a minimum amount of buccal-lingual width of alveolar bone for implant success. Placement of the minimum acceptable diameter implant (3.3mm) in the mandibular anterior with adequate remaining thickness of bone on the buccal and lingual (1mm each) yields a minimum bone thickness of 5.3mm, or more clinically pertinent, 6mm of bone.[36] In many patients, the implant bed preparation requires flattening and reduction of the ridge crest in order to achieve the 6mm minimum thickness. Necessary reduction of crestal bone to attain the minimum 6mm buccal-lingual thickness potentially brings the three key anatomic structures studied here closer to the osteotomy site, increasing the risk of encroaching upon to these structures. Similarly, restoration of dentition using fixed dental prosthetics also requires a minimum amount of apico-coronal space for prosthetic parts involved.[36] The amount of prosthetic space varies depending on the restorative material and type of final prosthesis. In many patients, reduction of alveolar bone is required in order to gain the minimum prosthetic space. Reduction of alveolar bone in the anterior mandible, again, has the potential to bring the crest closer to the three key anatomic structures studied here. Therefore, it is pertinent to examine edentulous scans to determine the distance from the residual ridge crest inferiorly to the region of the mandible where the buccal-lingual width is at least 6mm.

Finally, the cross-sectional shape of the anterior mandibular bone is of significant interest. Implant-based rehabilitation in the anterior mandible can be compromised in cases of severe alveolar constriction, the so-called "hourglass mandible" variant.[37] It is defined as an osseous constriction at the alveolar-basal bone junction. According to Butura et al in 2011, the approximate incidence of the hourglass variant is about 3.98%.[37] This extreme narrowing of bone makes dental implant placement difficult, and often requires bone grafting procedures.[38,39]

Another treatment approach to dental implant placement in the hourglass mandible is to complete ostectomy past the bony constriction to an optimal width (6mm as discussed above). Furthermore, reduction of the alveolar bone potentially brings crestal bone nearer to the three key structures. Therefore, it is beneficial to further examine cross-sectional patterns of bone to not only identify the incidence of the hourglass variant, but also other potentially remarkable bony variations as well.

Rationale for the Study

Dental implants have become an important treatment modality in the esthetic, functional, and prosthetic rehabilitation of patients with partial and complete edentulism.[1] Dental implants have gained widespread popularity in prosthodontic rehabilitation including single tooth replacement, multiple teeth replacement, support for complete arch fixed dental prostheses, and retention for removable complete and partial overdentures. Each of these treatment modalities includes at least two implants in the anterior mandible, usually at the positions of the lateral incisors or canines. There are three key anatomic structures in this area that are at significant risk of injury during surgical implant placement: the sublingual artery, the submental artery, and the mandibular incisive canal (MIC).

Quantitative data regarding precise location or percentage of variability of the sublingual artery, submental artery, and the MIC in dentate and edentulous patients is helpful to clinicians planning surgery in the anterior mandible. Currently, there is a lack of standardized measurements of these three vital anatomic structures. Furthermore, anatomy can vary in dentate and edentulous patients. As current clinical consensus or standard of care does not require a CBCT analysis prior to implant surgery, the risk for vascular and neurologic complications

during surgery performed in an outpatient setting is significant for clinical and medico-legal reasons. Furthermore, potential negative outcomes of these injuries have been documented to result in substantial paresthesia and pain from neural damage, and life-threatening hemorrhage leading to airway compromise from vascular injury.

From a clinical standpoint, CBCT analysis of all cases requiring surgery of the anterior mandible may be prudent, but it is not always possible or realistic. Modern CBCT (or CBVI) machines provide minimal radiation exposure and have been accepted to be very safe.[40] With the popularity of implant dentistry and advancement of associated technology, there is a need for scientific standards for clinicians to use when CBCT analysis is not employed. Therefore, this observational study seeks to determine if any standardized measurements of key anatomic structures can be determined via CBCT in dentate and edentulous patients in order to accurately predict mandibular surgical anatomy. Additionally, results from this study can offer "safe zones" and measurement guidelines to clinicians (not using CBCT) to help improve their surgical outcomes and minimize risks of morbidity for patients.

OBJECTIVES & HYPOTHESIS

Research Objectives

This study used cone beam computed tomography to examine the following characteristics of 125 edentulous and 100 dentate mandibles in order to know:

- The incidence of visualization of the perforation of the lingual cortex and silhouette of the sublingual artery at the midline in dentate and edentulous patients.

- The incidence of visualization of the perforation of the lingual cortex and silhouette of the submental artery at the midline in dentate and edentulous patients.

- The average distance from the inferior cortical border of the anterior mandible to the superior border of the sublingual artery at the midline in dentate and edentulous patients.

- The average distance from the inferior cortical border of the anterior mandible to the superior border of the submental artery at the midline in dentate and edentulous patients.

- The incidence of visualization of the silhouette of the mandibular incisive canal in the anterior mandible bilaterally in dentate and edentulous patients.

- The average distance from the inferior cortical border of the anterior mandible to the superior border of the mandibular incisive canal measured at lateral incisor and canine regions bilaterally in dentate and edentulous patients.

- The average diameter of the mandibular incisive canal in the anterior mandible measured at lateral incisor and canine regions bilaterally in dentate and edentulous patients.

- The average distance from the residual ridge crest inferiorly to the region of the mandible where the buccal-lingual width is at least 6mm at lateral incisor and canine regions bilaterally in edentulous patients.

- The various cross-sectional shapes of the anterior mandible at the midline.

Hypothesis

This study is a cross-sectional, non-experimental, observational study to define baseline

information related to anatomic landmarks in the anterior mandible. As a result, there are no null

hypotheses that were constructed in this study.

MATERIALS AND METHODS

CBCT Selection

University of Connecticut Health Center Institutional Review Board approval was obtained and was granted an exemption, as non-identifiable data was examined and collected in this study (Project number: UCHC-14-1107). A total of 225 cone beam computed tomography (CBCT) scans were selected for use from the Oral and Maxillofacial Radiology archives at the University of Connecticut School of Dental Medicine, Farmington, CT, and Pi Dental Center, Fort Washington, PA. This amounted to CBCT scans of 100 dentate subjects and 125 edentulous subjects.

The inclusion criteria for CBCT selection was as follows:

- Dentate scans must have had at least the mandibular six anterior teeth present (canine to canine)
- Edentulous scans must have been either completely edentulous in the mandible or partially edentulous with at least the mandibular anterior teeth missing (canine to canine)
- The anterior mandible must have included the entire height of the mandible with no field-of-view cuts
- Scans must have been full-volume, or at least have included the maxillary hard palate
- Images must have been of adequate resolution/diagnostic quality

The exclusion criteria for eliminating a CBCT scan was as follows:

- Any scan that did not satisfy any of the requirements listed in the inclusion criteria
- Any scan with "radiographic noise" that did not allow measurements to be recorded in the planning software

- Any scan that did not allow adequate manipulation of the image in the planning software due to technical errors

- Any scan that included maxillofacial trauma, orthognathic surgery, congenital anomalies, pathology, or reconstruction

CBCT Analysis

No personal identifiers were recorded from scans that were identified for use in the study. Demographic information including age and gender were recorded. The selected CBCT scans were copied to an encrypted and passcode protected external hard drive for use by the sole evaluator. Analysis of each CBCT scan was completed as follows:

- One investigator underwent calibration training with a board-certified oral and maxillofacial radiologist prior to commencement of the study.

- In order to assess intra-operator reliability, repeated measurements on a random set of 30 samples (15 edentulous subjects, and 15 dentate subjects) was completed.

- Digital Imaging and Communications in Medicine (DICOM) files were analyzed on an implant planning software program (InVivo 5: Anatomage, San Jose, Calif). This software program was used on a single encrypted and passcode protected computer.

- CBCT scans were evaluated in a standardized position with the hard palate oriented parallel to the horizontal axis

- A standardized measurement tool within the software program was used to make measurements of the structures of interest to the nearest hundredth of a millimeter

- Serial sagittal sections were viewed perpendicular to the anterior mandible. Occurrence of visualization of the cross-sections of the sublingual and submental arteries at the

mandibular midline were recorded. Incidence was calculated after all scans were analyzed.

- Upon visualization of the sublingual and submental arteries at the midline in sagittal sections perpendicular to the anterior mandible, measurements were recorded from the inferior-most border of the mandible to the superior-most border of the sublingual and submental arteries as they enter the lingual surface of the mandibular bone.

- Serial sagittal sections were viewed perpendicular to the anterior mandible. Occurrence of visualization of the cross-section of the mandibular incisive canal was recorded. If visualized, measurements were taken from the inferior-most border of the mandible to the superior-most border of the mandibular incisive canal at the lateral incisor and canine regions bilaterally. A standardized mesial-distal distance deviating 5mm from the midline was used to denote the lateral incisor region and another 5mm from this site was used to denote the canine region in edentulous scans.

- Serial sagittal sections were viewed perpendicular to the anterior mandible. If visualization of the cross-section of the mandibular incisive canal was observed, the greatest dimension diameter of the mandibular incisive canal was measured to the nearest hundredth of a millimeter at the lateral incisor and canine regions bilaterally.

- Edentulous scans only: Serial sagittal sections were viewed perpendicular to the anterior mandible. Using the measurement tool, the distance from the superior-most position on the crest of the residual ridge to the height at which the facial-lingual thickness of the mandible is 6mm in the area of the lateral incisors and canines was measured bilaterally.

- A cross-section perpendicular to the anterior mandible at the midline was viewed and mandibular cross-sectional bone patterns were recorded.

Statistical Analysis

Data subjected to statistical analysis:

- Percent occurrence of visualization of the sublingual artery at the midline

- Percent occurrence of visualization of the submental artery at the midline

- Mean distance of the sublingual artery to the inferior cortical border of the anterior mandible at the midline

    o Difference in the mean distance of sublingual artery to the inferior cortical border in dentate and edentulous scans

- Mean distance of the submental artery to the inferior cortical border of the anterior mandible at the midline

    o Difference in the mean distance of sublingual artery to the inferior cortical border in dentate and edentulous scans

- Mean distance from the superior border of the incisive canal to the inferior cortical border of the anterior mandible

    o Difference in the mean distance of superior border of the incisive canal to the inferior cortical border in dentate and edentulous scans

- Mean diameter of the incisive canal in the anterior mandible

    o Difference in the mean diameter of the incisive canal in dentate and edentulous scans

- Mean distance from the edentulous residual ridge crest inferiorly to the region of the mandible at lateral incisor and canine region where the buccal-lingual width is at least 6mm

- Percent occurrence of different cross-sectional shapes of the anterior mandible at the midline.

- Association of age with cross-sectional mandibular shape

All data were recorded in Microsoft Excel data sheets before statistical analysis. All of the statistical analyses were performed the statistical software R 3.1.2. (R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/)

First, the variables examined in this study were classified into categorical variables and discrete/continuous variables. In the descriptive data analysis, each categorical variable was summarized with frequencies and percentages. Each continuous/discrete variable was summarized with mean and standard deviation. Among the discrete/continuous variables, the left and right side data for bilateral measurements were averaged. The intra-class correlation co-efficient with a 95% confidence interval were calculated to evaluate the reliability of each distance measurement using the twice-evaluated data of 15 edentulous scans and 15 dentate scans.

Edentulous and dentate scans were compared using population means with respect to each continuous variable by two-sample t-test or Wilcoxon rank sum test. The Shapiro-Wilk test was applied to each sample to test for normality of the distribution. If both p-values were greater than 0.05, a two-sample t-test was performed; otherwise, a Wilcoxon rank sum test was used. For each categorical variable with two outcomes, the outcome distributions between edentulous and dentate scans were compared using the Fisher's exact test. For the only categorical variable with more than 2 outcomes, cross-sectional shape of the anterior mandible, the distributions of each

mandibular shape were compared using a Fisher's exact test. An overall chi-square test was not used for mandibular shape. Instead, multiple Fisher's exact tests were used because of the rarity of some shapes within the edentulous and dentate groups. An alpha value of 0.05 was chosen to test for any statistical significance.

RESULTS

This study sought to uncover average measurement values of anterior mandibular anatomic structures and compare similarities or differences in these measures between edentulous and dentate populations. In all, this study utilized a total of 125 edentulous CBCT scans and 100 dentate CBCT scans with ages ranging from 18 to 85 years old.

Intra-Operator Reliability

In order to determine the validity of any results that would be obtained in this study, a pilot evaluation of 15 edentulous and 15 dentate CBCTs in duplicate was first carried out to establish intra-rater reliability of the sole evaluator. Measures for the first and second replicates were recorded and intra-class correlation coefficients (ICC) were established for all measurements (Table 1). Most measures demonstrated a high degree of reliability between the first and second replicates with ICC values exceeding 0.95, with some notable exceptions. The distributions of these few exceptions are depicted in Figure 1, and consist of ICC of 0.89 and 0.88 for the diameter of the MIC at the lateral incisor position on the left and right sides respectively in edentulous scans. ICCs of 0.22 and 0.83 were also noted for the diameter of the MIC at the canine position on the left and right respectively in dentate scans. On closer examination, this was most likely due outliers, small N, and a small scale on the order of hundredths of a millimeter. Structures that were not analyzed, or where no comparison could be made were recorded as "NA."

Demographic Data

This study recorded basic demographic data, such as age and gender, for further exploration of possible anatomical changes related to age or gender. The age range of subjects in this study spanned from 18 to 85 years old. The gender distribution in edentulous scans was 48% female and 52% male, while the dentate scans had 57% female and 43% male (Table 2).

Incidence of Visualization of Key anatomic Structures

The overall incidence of visualization of the SLA in edentulous scans was 100%, and in dentate scans was 98% (Figure 2, Table 2). The incidence of visualization of the SMA in edentulous scans was found to be 94%, and in dentate scans was 88% (Figure 2, Table 2). The MIC had the lowest visualization rate, at 61% for edentulous scans, and 59% for dentate scans (Figure 2, Table 2). Though each group demonstrated slight differences, none of the differences in visualization noted between dentate and edentulous CBCTs were significant.

Measurements to Anatomic Structures

Sublingual Artery

Measurements from the inferior border of the mandible to the superior-most border where the sublingual artery (SLA) pierces the mandibular lingual cortex were made in edentulous and dentate scans. The average distance from the inferior border to the SLA in edentulous scans was 15.31mm ± 2.15 (mean ± SD) (Figure 3A). For dentate scans, the average distance was 15.91mm ± 1.72 (mean ± SD). This difference was statistically significant with a p-value of 0.042 (Table 2).

<u>Submental Artery</u>

Measurements from the inferior border of the mandible to the superior-most border where the submental artery (SMA) pierces the mandibular lingual cortex were made in edentulous and dentate scans. The average distance from the inferior border to SMA in edentulous scans was 5.2mm ± 2.46, and in dentate scans was measured to be 4.85mm ± 2.46 (Figure 3B). The difference between edentulous and dentate scans was not significant, with a p-value of 0.185 (Table 2).

<u>Mandibular Incisive Canal</u>

Table 3 depicts the bilateral comparison of subjects for measurements from the inferior border of the mandible to the MIC, as well as the diameter of the MIC at the locations of the lateral incisors and canines for edentulous and dentate CBCT scans. The majority of these measures were not significantly different between the right and left sides, which allowed us to combine data from the right and left sides with confidence. However, of note, there were two measures that were determined to be statistically significant between the right and left sides. These measures were the distance from the inferior border of the mandible to the MIC at the lateral incisor and canine sites. However, upon further inspection, the mean values for each comparison were separated by less than 0.9mm, and thus the difference was determined not to be clinically significant.

In edentulous scans, the MIC at the positions of the lateral incisors and canines was visualized 76% and 83% of the time, respectively. The mean diameter of the MIC was determined to be 1.44mm ± 0.23 at the lateral incisor position, and 1.50mm ± 0.27 at the canine position (Table 2). In dentate scans, the MIC at the positions of the lateral incisors and canines

was visualized 59% and 78% of the time, respectively. The mean diameter was noted to be 1.42mm ± 0.21 at the lateral incisor site, and 1.52mm ± 0.29 at the canine site. The difference in MIC diameter measured between edentulous and dentate scans was determined not to be statistically significant (Figure 3C-D).

The distance from the inferior border of the mandible to the superior border of the MIC was also of interest. At the lateral incisor site, this distance was 11.17mm ± 1.85 in edentulous scans, and 14.33mm ± 2.38 in dentate scans (Table 2). This was difference was determined to be statistically significant with a p-value <0.0001 (Figure 3E). Likewise, at the canine site, this distance was measured to be 11.16mm ± 1.75 in edentulous scans, and 13.70mm ± 2.64 in dentate scans. This difference, too, was considered to be statistically significant with a p-value <0.0001 (Figure 3F). These differences between dentate and edentulous scans could potentially be attributed to bony changes during remodeling post-extraction of teeth.

Minimum Anterior Mandibular Width for Implants

Rehabilitation of the dentition using dental implants requires a minimum amount of buccal-lingual width of alveolar bone. The minimum buccal-lingual thickness of bone required for a regular diameter implant (4 mm) is approximately 6mm. In edentulous patients, implant bed preparation requires reduction of the ridge crest in order to achieve this minimum thickness. Because implants in the anterior mandible of edentulous patients are most commonly placed bilaterally in the lateral incisor or canine sites, measurements were taken at each of these two sites bilaterally. It was necessary to evaluate the measurements for the right and left sides of each CBCT to determine if the values for each site could be combined. Table 3 depicts the bilateral comparison of measurements from the alveolar crest inferiorly to where the ridge

thickness was 6mm at locations of the lateral incisors and canines for edentulous CBCT scans.

The differences between the right and left at the lateral incisor and canine sites were not

statistically significant, and therefore, could be combined confidently into one measure. The

distance from the crest of the residual ridge to a minimum 6mm width at the lateral incisor site

was 4.49mm ± 3.61, and the canine site was 4.27mm ± 3.37. This suggests that on average, in

edentulous ridges, approximately 4-5mm of alveoloplasty may be required to achieve the

minimum buccal-lingual width of bone for implant placement.

Mandibular Cross-Sectional Morphology

An alternate goal of this study was to examine the diversity of cross-sectional shapes of

the anterior mandible at the midline and potentially classify the shapes. Based on commonly

occurring morphological shapes, a classification system was developed. Figure 4 depicts these

morphological shapes, and categorizes mandibular cross-sections into the following groups:

hourglass, pear, sickle, ovoid, and triangular.

The incidence distribution for these shapes varied between edentulous and dentate

mandibles. For edentulous patients, the percentage of occurrence was as follows: hourglass 1%,

ovoid 26%, pear 53%, sickle 4%, and triangular 17% (Figure 5, Table 2). For dentate patients,

the percentage of occurrence was slightly different: hourglass 3%, ovoid 0%, pear 58%, sickle

29%, and triangular 10%. The differences between dentate and edentulous mandibles were not

significant for the hourglass, pear, and triangular shapes. However, the differences between

edentulous and dentate mandibles were significant for ovoid shaped, and sickle shaped

mandibles with p-values <0.0001for both groups. This suggests that perhaps these two

morphological variants are highly dependent on the dental status of the patient, whereas the other three shapes are not.

Finally, the last comparison that was evaluated explored if any association existed between the age of the subject at the time of CBCT and the mandibular cross-sectional morphological shape. As demonstrated in figure 6, for both the edentulous and dentate groups, no statistical significance was found between mandibular shape and age.

DISCUSSION

The purpose of this study was to explore surgically pertinent anatomical differences between edentulous and dentate mandibles, and establish average measurement guidelines for particular anatomic structures, namely the sublingual artery, submental artery, and the mandibular incisive canal. Extensive literature has documented the general morphological changes that take place over time in the edentulous mandible after loss of dentition.[42] However, to date, no known studies document the specific changes that may happen to the surrounding key anatomical structures. This study sought to explore if any differences in specific anatomy could be determined in edentulous and dentate mandibles.

First, calibration of the evaluator for this study was of prime importance in order to establish reliability of the results. Overall, reliability was very high for the majority of categories. In the four categories where reliability was <0.95, the groups had small sample numbers and contained one or two severe outliers. This test of intra-rater correlation established the reliability of all of the results in the study.

The reference point for data measurements that was used in this study was the inferior border of the mandible. The inferior border of the mandible is considered to be a stable landmark throughout life, and its position is not affected by the presence or absence of teeth and subsequent alveolar resorption. The demographic composition of the edentulous and dentate groups demonstrated a significant difference in age between the edentulous and dentate groups with the mean ages being 63.2 and 60.05 years old, respectively. Though this difference was statistically significant, the clinical significance between 63 and 60 years old most likely irrelevant. The composition of males and females in both the edentulous and dentate groups was not significantly different.

The sublingual artery (SLA) and submental artery (SMA) both had high incidence of visualization on CBCT in both edentulous and dentate scans. The SLA was visualized 100% of the time in edentulous scans, and 98% of the time in dentate scans. Furthermore, the SMA was visualized 94% of the time in edentulous scans, and 88% of the time in dentate scans. As these two vascular structures are in a potentially hazardous area with serious implications if injured during implant surgery, providers utilizing CBCT imaging should always attempt to locate these structures with a do so with high degree of success. Additionally, clinicians not current utilizing CBCT for anterior mandibular implant placement should reconsider this option. On the other hand, the mandibular incisive canal (MIC) was only visualized 61% of the time in edentulous scans, and 59% of the time in dentate scans. This is most likely due to the intraosseous nature of the canal. As it courses medially from split at the mental foramen, it traverses through trabecular bone, and thus approximately 40% of the time can be lost in medullary spaces. This finding is of important value to clinicians as large mandibular incisive canals may be misdiagnosed as trabecular spaces and larger trabecular spaces may be potentially misdiagnosed as mandibular incisive canals.

This study sought to establish average measurements that may be useful to clinicians as guidelines for the location of the SLA, SMA, and MIC. On average, the SLA in edentulous subjects was 15.31mm from the inferior border of the mandible, and in dentate subjects was found to be 15.91mm from the inferior border of the mandible. Though this difference was found to be statistically significant, it is likely not clinically significant. As a result, a clinician not utilizing CBCT for anterior mandibular implant placement may use a distance approximately 15-16mm superior to the inferior border of the mandible as a general guideline for the location of the SLA in both edentulous and dentate patients.

Additionally, the SMA was found on average to be 5.2mm from the inferior border in edentulous subjects, and 4.85mm from the inferior border in dentate subjects. This difference was not found to be statistically significant. Thus, a generalized measurement of approximately 5mm superior to the inferior border of the mandible can serve as a general guideline for the location of the SMA in both edentulous and dentate patients.

Measurements for the MIC were conducted bilaterally. This was done in order to account for the bilateral and separate nature of this anatomic structure. The MIC is the medial continuation of the inferior alveolar canal after the mental foramen. Because of the slight anatomical variation that might exist bilaterally, both sides were accounted for. The average diameter of the MIC at the lateral incisor and canine regions for edentulous and dentate subjects ranged from 1.42-1.52mm. This is consistent with other studies in the literature which cite average diameters of 1.2mm,[43] 1.3mm,[26] and a range from 0.48mm-2.9mm.[25] Furthermore, average measurements from the inferior border of the mandible to the superior border of the MIC at the lateral incisor and canine regions yielded averages of 11.17mm and 11.16mm respectively in edentulous subjects. In dentate subjects, these averages were statistically significantly different yielding averages of 14.33mm and 13.70mm at the lateral incisor and canine respectively. Thus, guideline measurements for the MIC in edentulous subjects can be approximately 11mm from the inferior border of the mandible, and in dentate subjects approximately 14mm from the inferior border of the mandible. This difference might possibly be explained by the remodeling of bone post-extraction in edentulous patients as root apices are in close proximity to this anatomical structure. These measurements are inconsistent with existing literature by Mraiwa et al which sites this distance to be approximately 7.2mm from the inferior

border in cadaver studies.[26] This study, however, did not note the dental status of the cadavers and only included an evaluation of 50 samples.

Rehabilitation of the edentulous anterior mandible using implants requires a minimum buccal-lingual bone width of 6mm for regular diameter implants for predictable implant success.[36] Another facet of this study sought to investigate the average amount of alveolar bone reduction needed in order to achieve a minimum buccal-lingual bone width of 6mm. Many times, the implant bed preparation requires flattening and reduction of the ridge crest in order to achieve this minimum thickness. On average, the lateral incisor site required 4.49mm of bone reduction, and the canine site required 4.27mm. However, for both of these sites, the standard deviations were comparatively large yielding ±3.61mm and ±3.31mm for the lateral incisor and canine respectively. Ostectomy (formerly called aveolectomy) in this region brings the crestal bone closer to the three anatomic structures discussed in this project: the SLA, SMA, and MIC. As a guideline, clinicians may use an approximated 4-5mm rule for bone reduction; however, good clinical judgement based on specific bone width and prosthetic space should ultimately be favored.

Finally, the cross-sectional shape of the anterior mandible was of particular interest in this study. To date, no classification system for cross-sectional shape of the anterior mandible exists. This is of significant interest as implant-based rehabilitation in the anterior mandible may be compromised in cases of severe alveolar constriction, better known as the so-called "hourglass mandible" variant.[37] To date, this is the only classified morphological shape, and is defined as an osseous constriction at the alveolar-basal bone junction.[37] As other morphological variants may have implications on implant placement, a classification system was defined based on commonly occurring cross-sectional shapes noted during CBCT evaluation. The classified

variants are as follows: hourglass, ovoid, pear, sickle, and triangular. The incidence of the

hourglass variant was 1% in edentulous subjects, and 3% in dentate subjects, with no statistical

difference between these two groups. This is within range reported by Butura et al in 2011 in

which the incidence of the hourglass variant was reported to be 3.98%.[37] In general, the majority

of edentulous and dentate subjects were noted to have the pear shaped cross-section with 53%

and 58% respectively. This difference was also not significant. The ovoid shape mandibles were

significantly different between edentulous and dentate patients with 26% and 0% respectively.

This is likely due to the absence of teeth causing to the rounded appearance of the alveolar crest.

Furthermore, the difference between edentulous and dentate subjects was significant for the

sickle shaped mandibles, totaling 4% and 29% respectively. The greater proportion of sickle

shaped mandibles in dentate subjects is likely influenced by the presence of teeth in the alveolus.

Finally, the mandibular cross-sectional shapes were compared with age to see if any

trends were present. No trends were noted, and no relationships could be established with the

present data. This could potentially be due to limited variation in age of subjects examined, or

ethnic or skeletal differences, and warrants future exploration.

The average anatomic guidelines presented in this project can be used not only directly in

a surgical setting in order to predict the location of the SLA, SMA, and MIC; but, also may be

helpful in as means of "feasibility analysis" on a 2-dimensional panoramic radiograph. The most

superior to these structures would be the first encountered in a top-down osteotomy preparation

technique. In the majority of cases, the most superior structure is the SLA, which is

approximately 15mm above the inferior border of the mandible. After consideration of

prosthetic space and implant length, if the provider determines that surgical intervention will

likely encroach on this region 15mm above the inferior border, a full CBCT analysis is

warranted. If not, then anatomical averages and 2-dimensional radiography may provide the

operator with enough information to confidently proceed with implant rehabilitation.

STUDY LIMITATIONS

The nature of this study included the following limitations:

- Though best efforts were made to avoid using CBCTs which appeared to have fresh extraction sites, time post-extraction or length of time edentulous could not be fully accounted for in the analysis of the edentulous subjects

- Though age range of patients was widespread (from 18-85 years old), the age distribution was generally clustered between the ages of 55-70 years old.

- Racial or skeletal associations (eg: class I, II, or III) could not be recorded due to the purely radiographic nature of this project.

- All observations were made by 1 observer, which may introduce bias in data gathering. However, this may also be viewed as a strength, as it eliminates heterogeneity; additionally, the intra-operator reliability testing for the pilot study of 30 samples showed high consistency in measurements.

CONCLUSIONS

As dental implants have gained widespread popularity in prosthodontic rehabilitation, the number of reports citing adverse events has increased as well. Quantitative data regarding precise location or percentage of variability of the sublingual artery, submental artery, and the mandibular incisive canal in dentate and edentulous patients is helpful to clinicians planning surgery in the anterior mandible. The current standard of care does not require CBCT analysis prior to implant surgery. Yet countless negative reports of severe injuries have been documented and can result in substantial paresthesia and pain from neural damage, or life-threatening hemorrhage leading to airway compromise from vascular injury.

Though CBCT analysis of all cases requiring surgery of the anterior mandible may be prudent, it is not always necessary or possible. With the increasing popularity of implant dentistry and advancement of associated technology, there is a need for scientific standards for clinicians to use whether CBCT analysis is utilized or not.

Based on the results of this study, the following conclusions were drawn:

- The incidence of visualization of the sublingual artery on CBCT was 100% for edentulous subjects and 98% for dentate subjects

- The sublingual artery was located approximately 15mm above the inferior border of the mandible

- The incidence of visualization of the submental artery on CBCT was 94% for edentulous subjects and 88% for dentate subjects

- The submental artery was located approximately 5mm above the inferior border of the mandible

- The incidence of visualization of the mandibular incisive canal on CBCT was 61% for edentulous subjects and 59% for dentate subjects

- The mandibular incisive canal was approximately 1.5mm in diameter at the lateral incisor and canine regions

- The mandibular incisive canal was located approximately 11mm above the inferior border of the mandible in edentulous patients, and approximately 14mm above the inferior border of the mandible in dentate patients

- The average distance from the residual ridge crest inferiorly to the region of the mandible where the buccal-lingual width is at least 6mm was approximately 4mm at the lateral incisor and canine regions in edentulous patients

- A new classification system for the cross-sectional morphology of the anterior mandible was characterized, and includes the following shapes: hourglass, ovoid, pear, sickle, and triangular. The pear shaped was the most common among both edentulous and dentate patients.

Overall, the results of this study may aid clinicians in achieving better clinical confidence and improved clinical outcomes for implant placement in the anterior mandible.

FUTURE RESEARCH

The use of implants in dentistry grows more widespread daily. The results of the current study offer some clinical guidelines for practitioners who perform any surgical or prosthetic intervention in the anterior mandible. Future studies can expand upon the foundation laid by exploring potential anatomic changes with age or length of time the subjects are edentulous. Furthermore, future correlations can be made exploring possible relationships between mandibular cross-sectional morphology and race, skeletal classification, or length of time that the subject has been edentulous. Finally, future studies could be conducted in a similar manner concerning the posterior mandible. This area also has a significant number of important, and challenging anatomic structures providers must be fully aware of prior to any surgical intervention.

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Figure 1. (A) Distributions of outlier intra-class correlation coefficients of mandibular incisive canal diameter measurements at the lateral incisor position bilaterally in edentulous CBCTs. (B) Distributions of outlier intra-class correlation coefficients of mandibular incisive canal diameter measurements at the canine position bilaterally in dentate CBCTs. Note the presence of outliers in each distribution.
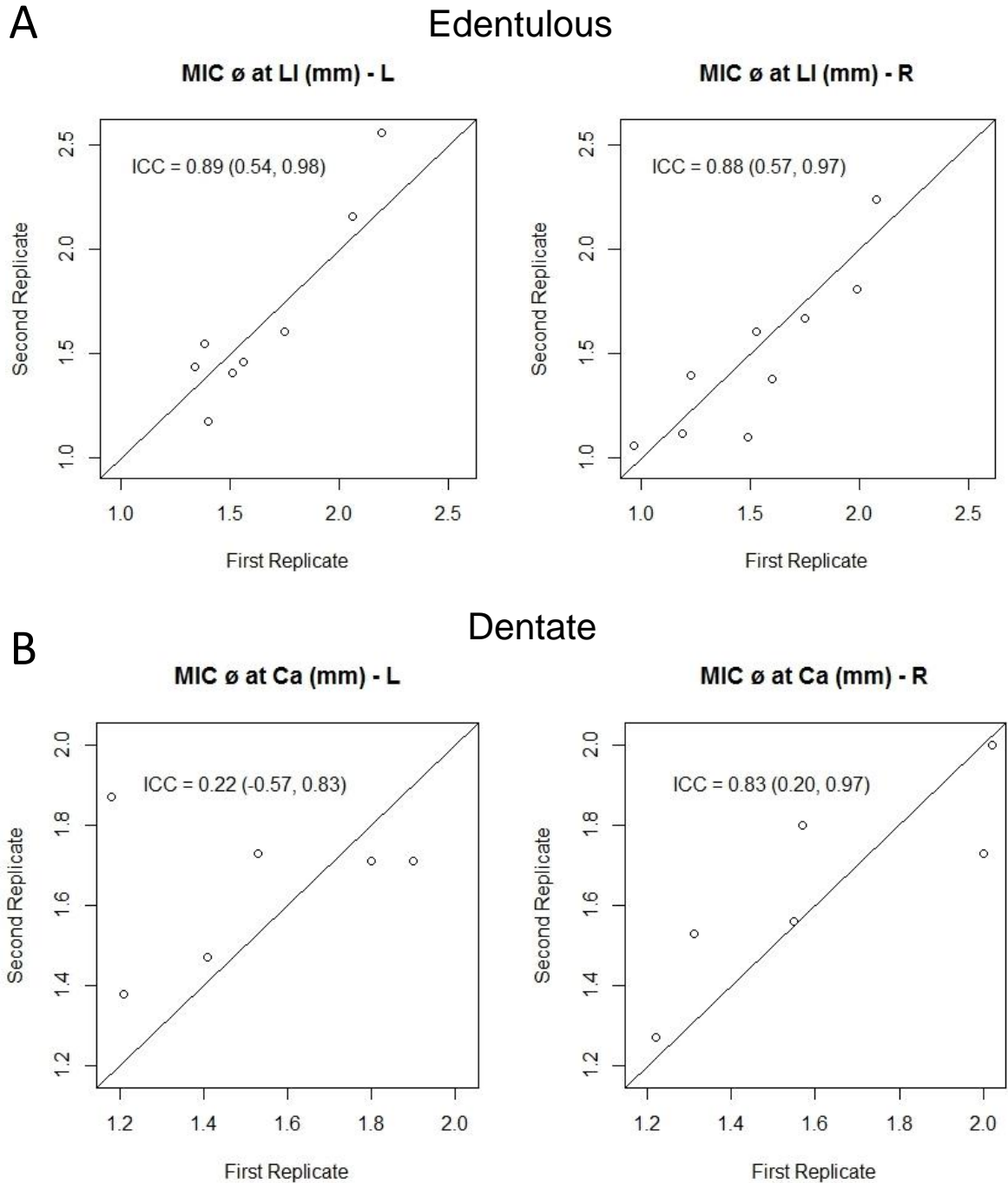
Figure 2. Incidence of visualization of the sublingual artery (SLA), submental artery (SMA), and mandibular incisive canal (MIC) in CBCT scans of 125 edentulous and 100 dentate CBCTs.
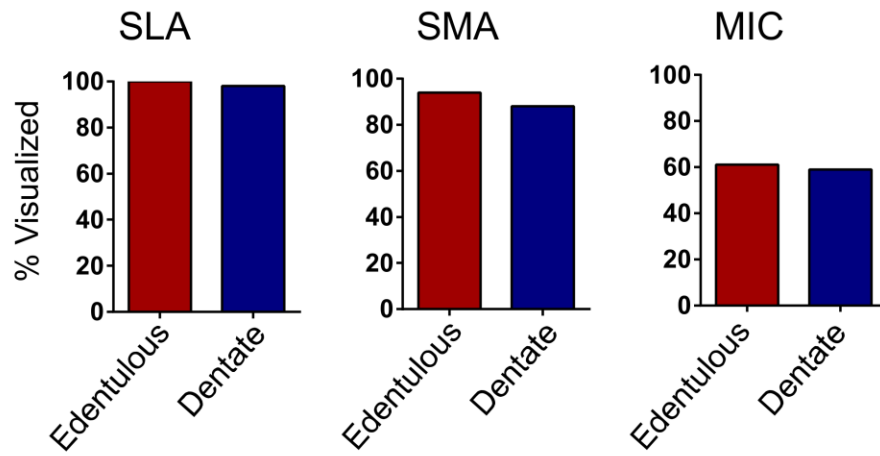
Figure 3. Scatter plots of measurements of noted anatomic structures. This includes the (A) distance measured from the inferior border of the mandible to the sublingual artery, (B) and the submental artery in edentulous and dentate CBCTs. (C) Measured diameter of the mandibular incisive canal at the lateral incisor region, and (D) the canine region in edentulous and dentate CBCTs. (E) Distance measured from the inferior border of the mandible to the mandibular incisive canal at the lateral incisor region, and (F) the canine region in edentulous and dentate CBCTs. All figures are presented as mean ± standard error of the mean (SEM) where error bars represent SEM. *P<0.05, **P<0.01, ***P<0.001, ****P<0.0001*
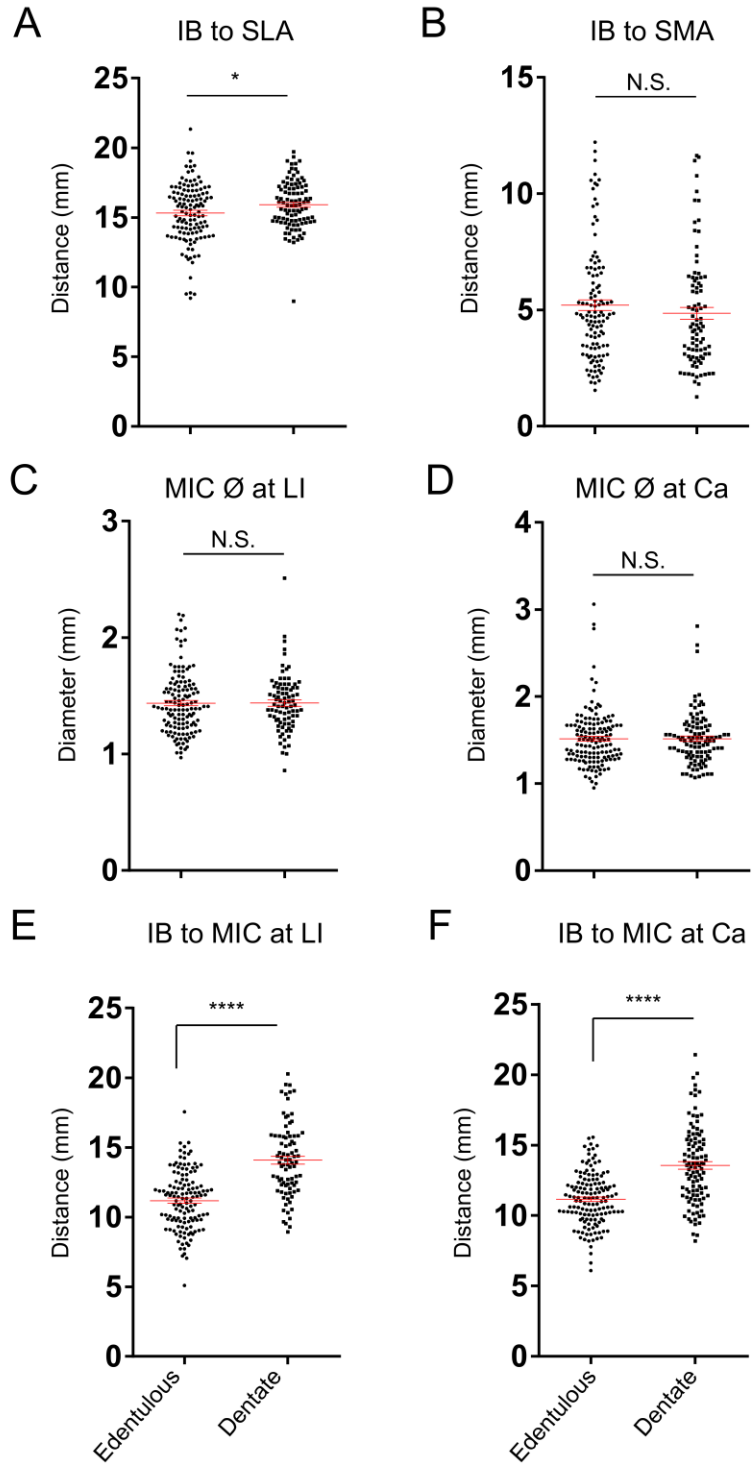
Figure 4. Sample cross-sectional shapes of anterior mandibular morphology in edentulous and dentate subjects. (A) Hourglass, (B) pear, (C) sickle, (D) ovoid, (E) triangular.

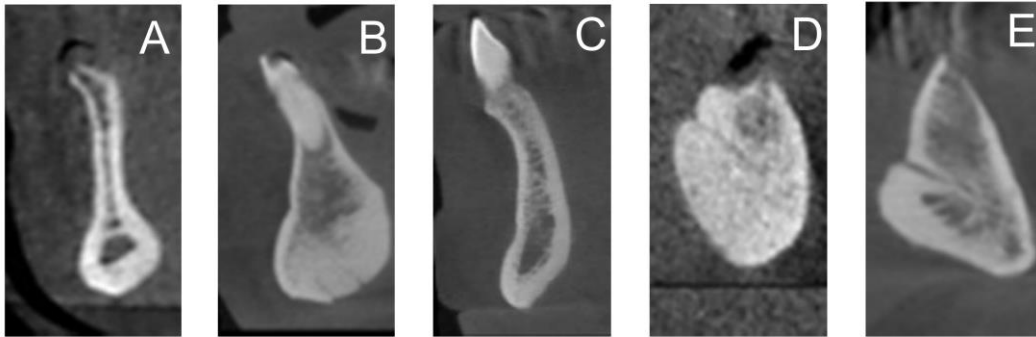**Figure 5.** Comparison of percent incidence of cross-sectional anterior mandibular shapes in 125 edentulous and 100 dentate CBCT scans.
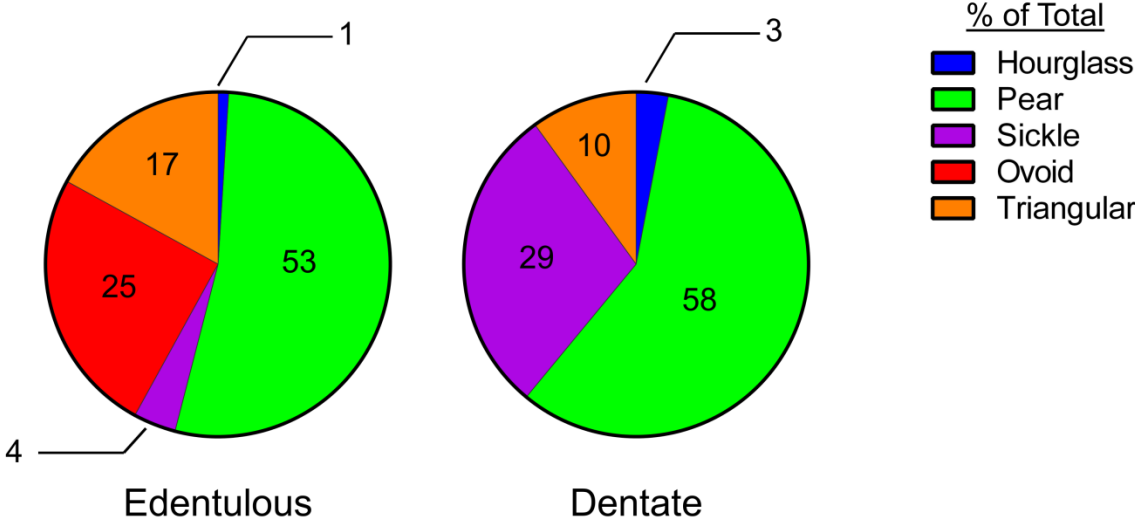
Figure 6. Scatter-plot distribution of mandibular cross-sectional shapes based on subject's age in edentulous and dentate CBCT scans. All figures are presented as mean ± standard error of the mean (SEM) where error bars represent SEM.
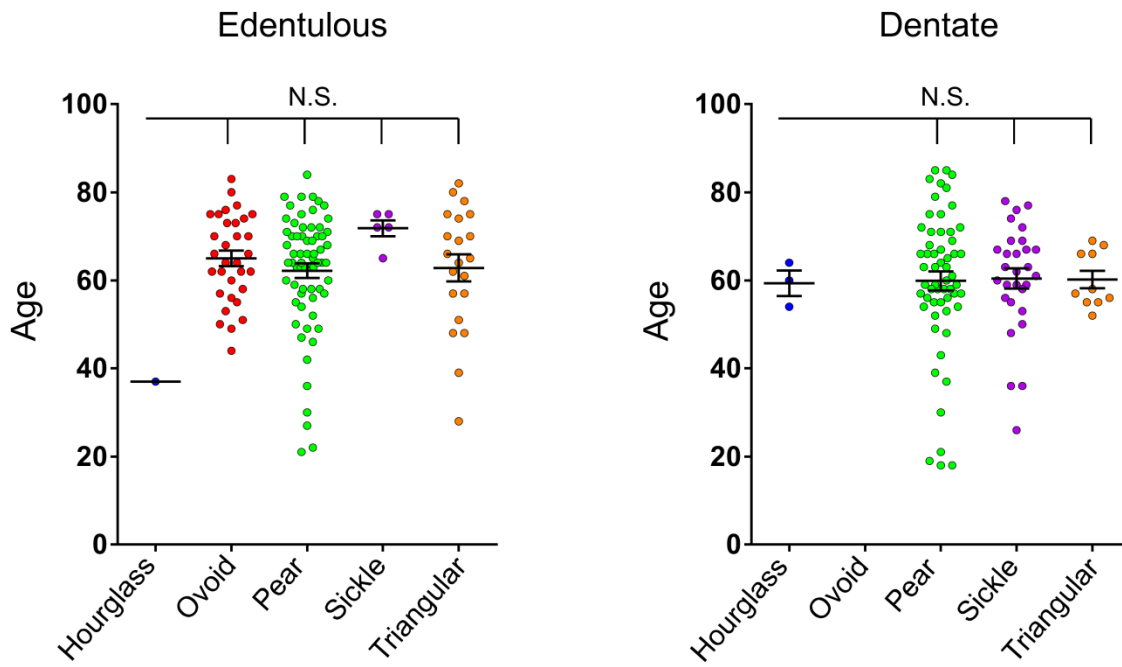
Table 1. Intra-class correlation coefficients for assessing operator reliability between first and second replicates. Structures that were not analyzed, or where no comparison could be made were recorded as "NA."

	Edentulous Scans (N=15)		Dentate Scans (N=15)	
	N	**Intra-class correlation**	**N**	**Intra-class correlation**
Distance (mm)				
IB to SLA	15	1 (0.99, 1)	14	1 (0.99, 1)
IB to SMA	12	1 (0.98, 1)	11	1 (0.99, 1)
IB to MIC at LI - L	8	0.99 (0.97, 1)	1	NA
IB to MIC at LI - R	9	0.99 (0.97, 1)	1	NA
IB to MIC at Ca - L	10	0.99 (0.94, 1)	6	1 (0.98, 1)
IB to MIC at Ca - R	9	0.98 (0.93, 1)	6	1 (0.99, 1)
Crest to 6mm width at LI - L	15	1 (0.99, 1)	NA	NA
Crest to 6mm width at LI - R	15	0.99 (0.96, 1)	NA	NA
Crest to 6mm width at Ca - L	15	1 (0.99, 1)	NA	NA
Crest to 6mm width at Ca - R	15	0.98 (0.93, 0.99)	NA	NA
Diameter (mm)				
MIC ø at LI - L	8	0.89 (0.54, 0.98)*	1	NA
MIC ø at LI - R	9	0.88 (0.57, 0.97)*	1	NA
MIC ø at Ca - L	10	0.97 (0.88, 0.99)	6	0.22 (-0.57, 0.83)*
MIC ø at Ca - R	9	0.95 (0.74, 0.99)	6	0.83 (0.20, 0.97)*

IB – inferior border of the mandible; SLA – sublingual artery; SMA – submental artery; MIC – mandibular incisive canal; ⌀- diameter; LI – lateral incisor; Ca – canine; L – left; R – right
*Measurements of lower reliability due to exceptional outliers

Table 2. Summary of demographic, incidence, and average measurement data for noted anatomical structures in 125 edentulous and 100 dentate CBCT scans.

	Edentulous Scans (N=125)		Dentate Scans (N=100)		P-value
Age	63.2 ± 12.72		60.05 ± 14.08		0.037
Gender					0.227
Female	60 (48%)		57 (57%)		
Male	65 (52%)		43 (43%)		
Sublingual artery visualized?					0.196
No	0 (0%)		2 (2%)		
Yes	125 (100%)		98 (98%)		
Distance from IB to SLA (mm)	15.31 ± 2.15		15.91 ± 1.72		0.042
Submental artery visualized?					0.162
No	8 (6%)		12 (12%)		
Yes	117 (94%)		88 (88%)		
Distance to from IB to SMA (mm)	5.2 ± 2.46		4.85 ± 2.46		0.185
Mandibular incisive canal visualized?					0.786
No	49 (39%)		41 (41%)		
Yes	76 (61%)		59 (59%)		
MIC ø at LI (mm)	58/76 = 76%	1.44 ± 0.23	35/59 = 59%	1.42 ± 0.21	0.809
MIC ø at Ca (mm)	63/76 = 83%	1.50 ± 0.27	46/59 = 78%	1.52 ± 0.29	0.792
Distance from IB to MIC at LI (mm)	58/76 = 76%	11.17 ± 1.84	35/59 = 59%	14.33 ± 2.38	<0.0001
Distance from IB to MIC at Ca (mm)	63/76 = 83%	11.16 ± 1.75	46/59 = 78%	13.70 ± 2.64	<0.0001
Distance from crest to 6mm width (mm)					
at LI	4.49 ± 3.61		NA		
at Ca	4.27 ± 3.37		NA		
Mandibular cross-sectional shape					
Hourglass	1 (1%)		3 (3%)		0.325
Ovoid	32 (26%)		0 (0%)		<0.0001
Pear	66 (53%)		58 (58%)		0.500
Sickle	5 (4%)		29 (29%)		<0.0001
Triangular	21 (17%)		10 (10%)		0.174

IB – inferior border of the mandible; SLA – sublingual artery; SMA – submental artery; MIC – mandibular incisive canal; ⌀- diameter; LI – lateral incisor; Ca – canine; L – left; R – right

Table 3. Comparison of bilateral right and left measurements of average distances from the

inferior border of the mandible to the mandibular incisive canal, and average diameter of the

mandibular incisive canal in edentulous and dentate CBCT scans; and, average distance from the

alveolar crest inferiorly to a minimum of 6mm anterior mandibular bone width in edentulous

CBCT scans.

	Edentulous Scans			Dentate Scans		
	Left	**Right**	**P-value**	**Left**	**Right**	**P-value**
Distance (mm)						
IB to MIC at LI	11.12 ± 2.28	11.25 ± 1.88	0.341	13.68 ± 2.56	14.58 ± 2.62	<0.0001
IB to MIC at Ca	11.11 ± 1.95	11.2 ± 1.77	0.410	13.26 ± 2.72	13.9 ± 2.84	0.025
Crest to 6mm width at LI	4.37 ± 3.68	4.61 ± 3.79	0.517	NA	NA	NA
Crest to 6mm width at Ca	4.28 ± 3.55	4.27 ± 3.54	0.974	NA	NA	NA
Diameter (mm)						
MIC ø at LI	1.45 ± 0.27	1.42 ± 0.26	0.232	1.45 ± 0.28	1.42 ± 0.2	0.757
MIC ø at Ca	1.5 ± 0.29	1.54 ± 0.36	0.118	1.52 ± 0.31	1.51 ± 0.28	0.888

IB – inferior border of the mandible; SLA – sublingual artery; SMA – submental artery; MIC – mandibular incisive canal; ø - diameter; LI – lateral incisor; Ca – canine; L – left; R – right