Mandibular morphological variation: implications for fracture repair

by

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DECLARATION

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ABSTRACT

Achieving a predictable clinical outcome during mandibular fracture repair necessitates thorough knowledge of variations of the neurovascular bundle, the location of tooth roots and bone quantity in the region of interest. In South Africa, the prevalence of mandibular body fractures due to alcohol-related interpersonal violence is increasing and is largely stratified socio-economically. Approximately 80% of people presenting with mandibular fractures rely on the resource-limited public health care system. In addition, South African population groups have a high prevalence of structures resembling accessory mental foramina (AMF) which may impede fracture fixation and outcomes. These considerations form the basis of this study which aimed to define population specific information on interforaminal variations and assess their applicability in clinical decision-making prior to fracture repair, using dry mandibles.

Hemi-mandibles (N = 213) with known age and varying tooth loss patterns were obtained from four ancestry and sex subgroups, namely South African Coloured (SAC) females, SAC males, Black (SAB) males and White (SAW) males. The location of the mental foramen (MF) and AMF was determined in relation to mandibular topographical landmarks. Buccal cortical plate (BCP) and buccal bone thickness was assessed at 12 points – four points on transverse planes through, superior, and inferior to the MF midpoint. Transverse planes correspond with possible locations for mini-plate fracture fixation and the four points on each plane corresponds with locations for mono-cortical screw insertion.

The MF was most commonly located between the first and second premolar teeth and the distance from the symphysis menti to the anterior border of the MF was smaller in SAC males when compared to SAC females. However, this parameter had a greater reading on right hemi-mandibles of SAB males when compared to SAC males. Tooth loss was associated with a decreased height of the mandible superior to the MF and age was associated with an increased MF diameter. Accessory mental foramina were observed in 6.54% of hemi-mandibles and was most commonly located mesial and superior to the MF. The BCP differed between subgroups and showed negative associations with tooth loss and age at selected assessment points. The buccal bone was thickest at the foraminal transverse plane when compared to superior and inferior transverse planes. It was thicker in SAC females when compared to SAC males on the inferior transverse plane of left hemi-mandibles. Overall, the influence of tooth loss and age on mandibular morphology did not vary between sex and ancestral subgroups.

Results show that in comparison to superior and inferior transverse planes, the foraminal transverse plane had the lowest risks for inadvertent injuries to vital structures. Risks on this plane increased from 1.9 to below 8% for screw lengths 4 – 8 mm bilaterally. These findings expand population-specific knowledge of anatomical variations which could aid clinical and preoperative decision-making in the repair of mandibular fractures in South Africa.

OPSOMMING

Dit is noodsaaklik om ‘n deeglike kennis te hê van variasies in die neurovaskulêre bondel, tandwortel apekse sowel as die hoeveelheid been teenwoordig, tydens die herstel van mandibulêre frakture. Die voorkoms van frakture in die mandibulêre liggaam as gevolg van alkohol-verwante interpersoonlike geweld, is aan die toeneem in Suid Afrika en is hoofsaaklik as gevolg van sosio-ekonomiese omstandighede. Ongeveer 80% van mense met mandibulêre frakture is afhanklik van die hulpbron-beperkte publieke gesondheidsstelsel. Bykomend, het Suid Afrikaanse populasiegroepe ‘n hoë voorkoms van structure wat lyk soos aksessoriese mentale foramina (AMF) wat moontlik fraktuur fiksering en fraktuur uitkomstes kan belemmer. Hierdie oorwegings vorm die basis van die huidige studie wat poog om populasie-spesifieke informasie op interforaminale variasies te definieer, asook hul toepaslikheid in kliniese en preoperatiewe besluitneming aangaande die herstel van frakture, deur die gebruik van droeë mandibula.

Hemi-mandibulae (N = 213) met bekende ouderdomme en met verskeie tandverlies patrone, is verkry vanaf vier geslags en populasie subgroepe naamlik Suid-Afrikaanse Kleurling vroue, Kleurling mans, Swart mans en Wit mans. Die posisie van mentale foramina (MF) en AMFs is bepaal in verhouding tot mandibulêre topografiese landmerke. Bukkale kortikale plaat (BKP) en bukkale been dikte is op 12 punte bepaal - vier punte op dwarsvlakke, superior, inferior en deur die midpunt van die MF. Dwarsvlakke stem ooreen met moontlike posisies vir mini-plaat fraktuur fiksering en die vier punte op elke vlak stem ooreen met inplantingspunte vir mono-kortikale skroewe.

Die MF was mees algemeen geleë tussen tand wortel apekse van die eerste en tweede premolaar tande. Die MF was nader aan die simfise geleë in linker en regter hemi-mandibulae van Kleurling vroue, maar was verder vanaf die simfise geleë in regter hemi-mandibulae van Swart

mans in verglyking met Kleurling mans. Tandverlies is geassosieer met ‘n afname in die mandibulêre hoogte superior tot die MF, en ouderdom is geassossieer met ‘n toename in die MF se deursnit. Aksessoriese mentale foramina het in 6.54% hemi-mandibulae voorgekom en is mees algemeen mesiaal en superior tot die MF geleë. Die BKP het verskille tussen subgroepe getoon by bepaalde assesseringspunte. Die BKP het ook negatiewe assosiasies met tandverlies en ouderdom getoon by bepaalde assesseringspunte. Bukkale been was dikker op die foraminale dwarsvlak in vergelyking met dwarsvlakke superior en inferior tot die foraminale dwarsvlak. Bukkale been was dikker in Kleurling vroue in vergelyking met Kleurling mans op die inferior dwarsvlak. Oor die algemeen het die invloed van tandverlies en ouderdom op mandibulêre morfologie, nie tussen geslag en populasiegroepe verskil nie.

Hierdie resultate dui daarop aan dat die foraminale dwarsvelak die laagste risiko vir onopsetlike beserings aan noodsaaklike structure in hou. Die risiko op hierdie vlak styg vanaf 1.9% tot onder 8% vir skroewe van 4 tot 8 mm in lengte. Hierdie bevindinge brei uit op reedsbestaande kennis van populasie-spesifieke anatomiese variasies wat die kliniese en preoperatiewe besluitnemingsproses vir die beplanning van interforminale fraktuur behandeling mag ondersteun in Suid-Afrika.

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DEDICATION

This thesis is dedicated to my sister, Jade Amber McKay. Your life has taught me that setting goals, and achieving them in the face of adversity, is a gift afforded to few. Thank you for reminding me to always count my blessings.

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ABBREVIATIONS

AC	Anterior crest
AL	Anterior loop
AMF	Accessory Mental foramen
ANOVA	Analysis of variance
BAC	Blood alcohol content
BCP	Buccal cortical plate
CAB	Cancellous bone
CBCT	Cone beam computed tomography
COB	Cortical bone
CT	Computed tomography
Fl1	4.5 mm lateral to the foraminal midpoint on the foraminal plane
Fl2	9 mm lateral to the foraminal midpoint on the foraminal plane
Fm1	4.5 mm mesial to the foraminal midpoint on the foraminal plane
Fm2	9 mm mesial to the foraminal midpoint on the foraminal plane
I	Inferior
IAN	Inferior alveolar nerve
ICC	Intraclass Correlation Coefficient
Il1	4.5 mm lateral to the foraminal midpoint on the inferior plane
Il2	9 mm lateral to the foraminal midpoint on the inferior plane
IM	Inferior border of the mandible
Im1	4.5 mm mesial to the foraminal midpoint on the inferior plane
Im2	9 mm mesial to the foraminal midpoint on the inferior plane
IPV	Interpersonal violence
K	Kappa
l	Lateral

m	mesial
MBB	Minimum buccal bone
MC	Mandibular canal
MF	Mental foramen
$MF_{(MAX)}$	maximum diameter of the foraminal midpoint
$MF_{(MIN)}$	minimum diameter of the foraminal midpoint
mm	Millimetres
MMF	Maxillomandibular fixation
NCC	Neural crest cells
ORIF	Open reduction and internal fixation
PDL	Periodontal ligament
PI	Position 1 of the mental foramen
PII	Position 2 of the mental foramen
PIII	Position 3 of the mental foramen
PIV	Position 4 of the mental foramen
PV	Position 5 of the mental foramen
PVI	Position 6 of the mental foramen
r	Pearson’s correlation coefficient
r^2	Coefficient of determination
r_s	Spearman’s correlation
RTA	Road traffic accidents
S	Superior
SAB	South African Blacks
SAC	South African Coloureds
SAW	South African Whites
SD	Standard deviation

Sl1	4.5 mm lateral to the foraminal midpoint on the superior plane
Sl2	9 mm lateral to the foraminal midpoint on the superior plane
SM	Symphysis menti
Sm1	4.5 mm mesial to the foraminal midpoint on the superior plane
Sm2	9 mm mesial to the foraminal midpoint on the superior plane
TMJ	Temporomandibular joint

CHAPTER ONE: INTRODUCTION

The mandible is the most fractured bone in the maxillofacial complex (Fasola, Obiechina & Arotiba, 2003; Ansari, 2004; Ferreira, Amarante & Silva, 2005; Mogajane & Mabongo, 2018). However, the body of the mandible is the most common fractured site (Ansari, 2004; Ferreira *et al.*, 2004; Eggensperger, Smolka & Scheidegger, 2007; Roode, 2007; Porter, Lownie & Cleaton-Jones, 2013). An increase in both the frequency and complexity of mandibular fractures due to interpersonal violence (IPV) has been noted over the years particularly in low socio-economic urban settings with escalating unemployment rates (Bowley *et al.*, 2004; Desai, 2007; Eggensperger, Smolka & Scheidegger, 2007; O'Meara, Witherspoon &Hapangama, 2012; Porter, Lownie &Cleaton-Jones, 2013; Mogajane &Mabongo, 2018).

Mandibular body fractures commonly occur through the mental foramen (MF) (de Souza Fernandes *et al.*, 2010a). Treatment of interforaminal fractures requires thorough knowledge of internal and external topographic variations of the neurovascular bundle, the location of tooth root apices as well as bone quantity in this region (Katranji, Misch &Wang, 2007; de Souza Fernandes, Rossi, *et al.*, 2010; Al-Jandan *et al.*, 2013; Iwanaga *et al.*, 2015; Voljevica, Talović &HaJsanović, 2015; Ravi *et al.*, 2017). These structures differ between population groups and are influenced by sex, dentition and age (Swasty *et al.*, 2009; Kalender, Orhan &Aksoy, 2012; Paraskevas, Mavrodi &Natsis, 2014). Findings on a single population may also vary depending on the imaging modalities available and employed (Imada & Fernandes, 2012; Neves *et al.*, 2014).

In South Africa, there is a need for cost and time efficient ways to repair mandibular fractures, with low risk for iatrogenic injuries, especially since 80% of the population rely on public health care (Porter, Lownie & Cleaton-Jones, 2013). Mini-plate fixation satisfies this need and is the most widely used hardware scheme for treating non-displaced fractures (Michelet, Deymes & Dessus, 1973; Sauerbier, Schön & Otten, 2008; Lazow & Tarlo, 2009; Bouloux, 2010).

Mini-plates are anchored to bone on biomechanically favourable regions in the mandible, referred to as ideal lines of osteosynthesis (Champy *et al.*, 1978; Koshy, Feldman & Chike-Obi, 2010). It comprises zones of tension and compression which experiences less dynamic force vectors during mandibular fracturing and has sufficient bony buttressing for mono-cortical screw anchorage. However, ideal lines of osteosynthesis frequently overlap with the roots of teeth in the premolar dento-alveolar region due to a markedly thinner buccal cortical plate (BCP) in this region (Borah & Ashmead, 1996; Ellis, 2011, 2012). Sensory disturbance following fracture fixation on ideal lines of osteosynthesis, have also been reported (Borah & Ashmead, 1996; Lazow & Tarlo, 2009). It is evident that achieving a predictable clinical outcome necessitates a thorough knowledge of population-specific information (Al-Jandan *et al.*, 2013; Talaat *et al.*, 2015). Variations of the MF position and number is documented for South African population groups (McKay, Tchokonte-Nana & Mbajiorgu, 2018; Laher & Wells, 2016); however, there is currently no data available on internal variations in this region. This investigation aims to define population specific information on interforaminal variations and assess their applicability in clinical decision-making prior to fracture repair.

CHAPTER TWO: LITERATURE REVIEW

Mandibular fractures are a major financial burden on the South African health care system (Desai, Lownie & Cleaton-Jones, 2010; Porter, Lownie & Cleaton-Jones, 2013; Mogajane & Mabongo, 2018) and impedes the quality of life of those affected. The complex interactions between different components within the masticatory system places stresses on the functioning mandible. To grasp the mechanisms altered during mandibular fracturing, the composition and structure of the mandible, both macro- and microscopically, needs to be appreciated. In this way, factors to ensure stability and functionality of fractured mandibles, can be identified.

The literature review will emphasize the following:

- Mandibular development, growth and remodelling with key focus on how its micro- and macro-structure influences its strength.
- Epidemiology of mandibular fractures with special attention to the role of alcohol usage on injury mechanisms.
- The most commonly employed fracture fixation hardware schemes, their indications and contraindications.
- Topographical variations in the mandibular body which may influence risks for iatrogenic injuries.
- The standard imaging modalities used in maxillofacial surgery and their limitations.

2.1. MANDIBULAR DEVELOPMENT

The mandible is the largest and strongest bone of the facial skeleton (McCormack *et al*., 2014; Humphries 2007). It is characterized by a U-shaped body connected to paired rami projecting posterosuperiorly to articulate with the temporal bone of the cranium via the temporomandibular joint (TMJ) (Srinivas Moogala *et al*., 2014). It constitutes seven anatomical locations, namely the symphysis, parasymphysis, body, angle, ramus, condylar and coronoid processes.

The mandible comprises cortical and cancellous components (Burr & Akkus, 2014). Mandibular cancellous bone (CAB) contains a thin medullary cavity – the mandibular canal (MC), which houses the inferior alveolar nerve (IAN), artery and vein. It is covered by cortical bone (COB) containing an endosteum on its internal surface which marks the boundary between COB and CAB. On its external surface, COB contains the periosteum – a thin layer of dense connective tissue containing microvasculature enveloping the entire mandibular cortex except the condylar head (Nanci 2017).

Bone modelling is the processes of bone deposition onto surfaces without necessarily being preceded by resorption. It gives a bone its shape and increase its mass (Sommerfeldt &Rubin, 2001). Various tissue types derived from the first branchial arch undergo patterning, fusion and extension to ensure modelling of the mandible and surrounding structures which includes the trigeminal nerve, terminal branches of the maxillary artery, muscles of mastication, lower lip and anterior portion of the tongue (Frisdal & Trainor, 2014).

2.1.1. Intramembranous ossification

Intramembranous ossification, also known as primary cartilage formation, encompasses the development of two hyaline cartilaginous bars namely, Meckel’s cartilages (Nanci 2017). Migration of mesenchymal neural crest cells (NCC) from the mid- and hindbrain to the first pharyngeal arch around the sixth gestational week, is responsible for the formation of these cartilages (Carlson, 2004; Hutchinson, 2011; Frisdal & Trainor, 2014). These cells are the precursors of osteoblasts which induce osteoid to form primary centres of ossification (Frisdal & Trainor, 2014).

Meckel’s cartilages are closely associated with mandibular development (Berkovitz 2017), as well as the branching of the mandibular nerve. The posterior division of the trigeminal nerve, namely the mandibular branch, innervates all masticatory muscles. Around its cranial end, this nerve bifurcates into a lingual nerve and an IAN, whose branches occupy the middle third of the cartilage. The distal third of Meckel’s cartilage is associated with branching of the IAN to form incisive and mental nerves (Nanci 2017).

These cartilages are encapsulated by a fibrous membrane. Around the seventh week of gestation, mesenchymal cell condensation within the membrane surrounding each cartilage bar forms a primary ossification centre (Frisdal & Trainor, 2014). These initial sites for ossification are located at the bifurcation of mental and incisive nerves (Berkovitz 2017). Ossification spreads to suspend the incisive nerve in a groove and forms the MF (Nanci 2017). Hereafter, it ensues mesialy towards the cartilaginous halves and backward to form a trough in which the IAN will be housed (Berkovitz 2017). Intramembranous ossification stops at the future mandibular foramen (Frisdal & Trainor, 2014).

2.2 MANDIBULAR GROWTH

Mandibular growth occurs in three ways, namely by: 1) endochondral ossification, 2) growth with alveolar processes and 3) subperiosteal appositional growth and bone resorption.

2.2.1. Endochondral ossification

This process is responsible for the formation of secondary cartilages and is therefore also known as growth by secondary cartilage. Although similar to intramembranous ossification in that mesenchymal cells are present, here mesenchymal cells differentiate into collagen-forming chondroblasts instead of osteoblasts (Leander 2011). Between the 10th and 14th gestational weeks, condensation of mesenchymal NCCs form cartilage deposits diverging posterosuperiorly away from Meckel's cartilage (Frisdal & Trainor, 2014). These cartilage deposits differentiate into condylar and coronoid cartilages via interstitial and appositional growth (Berkovitz 2017). Following differentiation, the former comprises the condylar head and neck, and the half of the ramus posterior to the mandibular foramen. Likewise, coronoid cartilages form coronoid processes and the half of the ramus anterior to the mandibular canal. This type of growth results in an increased height and length of the ramus. It also accounts for an increased intercondylar distance in the adult mandible (Mizoguchi *et al.*, 2013).

2.2.2. Growth associated with alveolar processes

Alveolar process development begins as soon as deciduous tooth germs reaches their early bell stage around the 11th and 12th gestational weeks. A space forms between the mandible and maxilla as growth ensues to accommodate tooth eruption. Bone deposition occur on each side of tooth germs so that developed teeth are surrounded by crypt-forming septa containing alveolar nerves and vessels. The neurovascular bundle that initially, was in close proximity to tooth germs, is now contained within its own bony MC (Berkovitz 2017).

2.2.3. Sub-periosteal appositional bone growth and bone resorption

Appositional growth is responsible for an increased breadth of bone. It encompasses bone deposition below the periosteum of the outer buccal cortical plate (BCP) at the posterior ramal border, anterior border of the coronoid processes and chin. Resorption occurs below the periosteum of the lingual cortical plate at each of these landmarks, except at the chin region. This results in an increased transverse dimension of the corpus, displacement of the coronoid processes and an adjusted thickness of the ramus throughout life (Martinez-Maza *et al.*, 2013).

2.3. MANDIBULAR REMODELLING

Bone remodelling is a lifelong process characterised by bone resorption coupled with bone deposition on a bone surface. Bone is designed to resist deformation during masticatory function (Sommerfeldt & Rubin 2001). Its mechanical properties differ in response to the function of an anatomical location and the direction of forces applied to it (anisotropy) (Goldstein 1987).

Wolf's law (Wolf, 1986), known as the law of bone remodelling, states that alterations in the internal structure of bone, including secondary external structural alterations, occur as a result of primary changes in the stresses on a bone. Supporting this theory is that of Frost (1983), which states that a threshold minimum effective strain is required to act as a mechanical stimulus for bone remodelling.

2.3.1. Mechanical properties related to bone micro-structure

Bone comprises a 65% inorganic component containing mainly hydroxyapatite, a 25% organic component containing mainly type 1 collagen fibres and 10% water. Collagen gives bone its elasticity, making bones tough and flexible. Hydroxyapatite influences a bone's strength by making it stiff and brittle (Nanci 2017). Both COB and CAB contain lamellae; however, differences in their microstructural composition gives them dissimilar mechanical properties.

2.3.1.1. Cortical bone

Cortical bone constitutes the bulk of a bone's mass. Its functional unit is the osteon which consists of up to 20 concentric lamellae. Collagen fibres contained within consecutive osteonal lamellae are arranged perpendicular to one another. This arrangement coupled with COB's low surface area-to-volume ratio, makes it strong and able to withstand great compressive forces (Sommerfeldt & Rubin, 2001).

2.3.1.2. Cancellous bone

Cancellous bone (CAB) comprises a network of rod- and plate-like trabeculae of different sizes, which is why it is also referred to as trabecular bone (Moon *et al*., 2004). Trabeculae contain primarily irregularly orientated collagen fibres. The lamellae of each trabecula is orientated parallel to it (Sommerfeldt & Rubin, 2001). Despite CAB constituting 20% of a bone's weight, it has a larger surface area compared to COB (Clarke 2008). This makes it tough, yet flexible, and therefore, resistant to tensile forces (Cowin & Hegedus, 1976; Sommerfeldt & Rubin, 2001).

2.3.2. Biomechanics of the mandible: the zones of tension and compression

Loading is the act of exerting a force on an object. Masticatory and occlusal loads are the primary drivers of bone remodelling (Nicholson & Harvati, 2006; Humphries, 2007; Ogawa & Osato, 2013). These loads are tightly regulated by peripheral feedback to muscle spindle- and periodontal ligament (PDL)- receptors, collectively referred to as periodontal mechanoreceptors (Türker 2002; Türker *et al.*, 2007).

Elevation and depression of the mandible is made possible by two main muscle groups namely, masticatory and suprahyoid muscles. Masticatory muscles include the temporalis, lateral- and medial- pterygoid, and masseter. With exception to the lateral pterygoid, these muscles elevate the mandible, allowing it to act as a lever around the TMJ (Srinivas Moogala *et al.*, 2014). Three suprahyoid muscles namely, the digastric, mylohyoid, and geniohyoid, work in concert with the lateral pterygoid to depress the mandible.

During mastication, a bite force is generated perpendicular to the mandibular occlusal plane in the posterior dental arch. A functional interface forms between teeth of the maxillary and mandibular arches, resulting in the mesial movement of teeth (Picton, 1962; Sommerfeldt & Rubin, 2001; McCormack *et al.*, 2014). This tooth movement stimulates elastic fibre PDL mechanoreceptors, which transmit chemical loads to COB via CAB and encourage bone deposition at muscle insertion sites (McCormack *et al.*, 2014). The strains produced by masticatory muscles also encourage bone deposition at muscle insertion sites, particularly temporalis and masseter muscles (Swasty *et al.*, 2009; Patriquin 2013; Oettlé 2014). The mandible's resistance to compression is greatest at muscle insertion points as a result of a thicker COB. Muscle insertion points are therefore referred to the zone of compression (Koshy, Feldman & Chike-Obi, 2010).

Mechanical pressure continuously applied to dental arches during occlusion results in alveolar CAB remodelling. Remodelling in this region is marked by an increased volume and thickness of compact plate-like trabeculae when compared to loosely structured and predominantly rod-like basal trabeculae (Moon *et al.,* 2004). PDLs act as suspensory ligaments by transmitting vertical occlusal forces unevenly as lateral forces to tooth sockets, and in doing so, prevents high stress levels on tooth roots. However, the action of PDLs causes the alveolar region of the mandible to experience varying degrees of tensile stresses (Atmaram & Mohammed, 1981). This coupled with mesial tooth movement which also places tensile strain on this region, causes the sub-apical region to experience tension, and is therefore referred to as the zone of tension. This zone is separated from the zone of compression by a line of zero force (Koshy, Feldman & Chike-Obi, 2010).

2.3.4. Factors influencing buccal cortical plate and cancellous bone

Masticatory muscles directly alter mandibular form at muscle insertion sites, but also influences the shape of bone through their role in generating a bite force. The following sections focuses on factors that influence muscle strength, and therefore, COB and CAB variations.

2.3.4.1. Influence of age and degree of dentition on buccal cortical plate

The mandibular cortex thickens considerably from 10- to 49-years-of-age. Hereafter, senescence results in a low bone mass and density turnover (Swasty *et al.*, 2009; Cassetta *et al.*, 2013a). Similarly, tooth loss is associated with a reduction in the forces applied to the mandible which leads to bone resorption (Martinez-Maza *et al.*, 2013; Oettlé 2014). The greatest degree of alveolar bone is resorbed within the first few years following tooth extraction (Mercier & Lafontant, 1979). Hereafter, resorption continues at a slower rate for the next 25 years, leaving only a residual ridge (Ozan *et al.*, 2013).

Older individuals with complete dentition generate a greater bite force which encourages bone maintenance (Schwartz-Dabney & Dechow, 2003). Despite this, Katranji and colleagues (2007) reported a thicker BCP in geriatric edentulous mandibles 3 mm apical to the alveolar crest in mesial, middle and lateral regions of the mandible when compared to the same regions in geriatric dentate mandibles.

2.3.4.2. Influence of sex on buccal cortical plate thickness

Pre-pubescent boys and girls have similar jaw heights and BCP thicknesses (Israel 1969). With the onset of puberty, males gain bone mass at an accelerated rate and in the adult, sex differences in bone mass favours men by over 13% (Israel, 1969; Walker & Kowalski, 1972). Generally, adult males have larger, more robust jaws with well-developed sites for muscle attachments (Kharoshah, Almadani & Ghaleb, 2010), and hence, thicker BCP and densities compared to females (Schwartz-Dabney & Dechow, 2003; Cassetta *et al.*, 2013a).

2.3.4.3. Ancestral variations of the buccal cortical plate

The BCP thickness varies between populations (Katranji, Misch & Wang, 2007; Al-Jandan *et al.*, 2013; Talaat *et al.*, 2015). Prognathic facial dimensions in Black individuals are, in part, ascribed to greater tooth sizes and a more than three-fold higher likelihood of exhibiting third molars compared to Caucasians (Hanihara & Ishida, 2005; Harris & Clark, 2008). Third molar presence is associated with an increased height of the mandible at the MF (Ogawa & Osato, 2013; Oettlé, 2014) and the height of the mandible has a positive influence on the BCP (Swasty *et al.*, 2009).

2.3.4.4. Influence of age and tooth loss on cancellous bone

Young individuals with complete dentition have a thinner CAB in apical and mesial regions of the mandible when compared to apical and lateral regions (Al-Jandan *et al*., 2013; Moon *et al*., 2004). In partially- and completely- edentulous mandibles aged between 56- to 90-years-of-age, the reverse is true, with no differences observed between partial and completely edentulous mandibles (Misch, Qu & Bidez, 1999; Katranji, Misch & Wang, 2007).

2.4. MANDIBULAR FRACTURES

A fracture is the disruption of the continuity of a bone when the external forces acting on the bone exceeds its innate elasticity (James, Nelson & Ashwill, 2014). The mandible is the tenth most fractured bone in the human body (Busuito, Smith & Robertson, 1986; Azevedo, Trent & Ellis, 1998). It requires four times the energy to fracture when compared to the maxilla (Huelke 1964). Despite this, fractures of the mandible are 1.78 times more common than maxillary fractures (Ansari 2004), and twice as common as zygomaticofacial fractures (Oji 1999), and thus, the most fractured bone in the maxillofacial complex (Adebayo, Ajike & Adekeye, 2003; Fasola, Obiechina & Arotiba, 2003; Ansari, 2004; Porter, Lownie & Cleaton-Jones, 2013; Mogajane & Mabongo, 2018).

Mandibular fractures may cause a variety of functional impairments including temporomandibular joint syndrome, salivary disorders, dysocclusion, soft tissue infection and osteomyelitis (Azevedo, Trent & Ellis, 1998; Scolozzi, Martinez & Jaques, 2009; Atilgan *et al.*, 2010). Fractures and associated surgical repair are also associated with significant financial implications (Porter, Lownie & Cleaton-Jones, 2013).

The mandible contains natural zones of compression and tension (Champy *et al.*, 1978; Sauerbier, Schön & Otten, 2008). Fractures occur at sites of tensile strain because bone has a greater resistance to compressive and shearing forces (Hodgson 1967). Irregularities exist within the mandible. They include convexities, concavities, foramina and notches. These irregularities, coupled with region-specific cross-sectional CAB and COB thicknesses (Halazonetis, 1968; Moon *et al.*, 2004; Katranji, Misch & Wang, 2007; Al-Jandan *et al.*, 2013; Cassetta *et al.*, 2013a), makes certain regions of the mandible inherently mechanically weaker, and therefore, incapable of absorbing great mechanical loads.

The dynamic force vectors created by masticatory and suprahyoid muscles is greater in fractured mandibles (Koshy, Feldman & Chike-Obi, 2010) and varies between different fractured sites and the direction of muscle strain at these sites (Swasty *et al*., 2009; Patriquin 2013; Oettlé 2014). With moderately severe external force, such as a blow to the face, the mandible will fracture at its weakest points (Halazonetis 1968). More severe forces results in fractures at sites of direct impact even when these sites are muscle insertion points with greater bone cross-sectional areas (Katranji, Misch & Wang, 2007). If an external force is extremely severe, the site of direct force application as well as distant sites will fracture (Huelke 1968).

2.4.1. Fracture aetiology

Verification of the mechanisms of injury not only helps to assess concomitant injuries (Koshy, Feldman & Chike-Obi, 2010), but also provides an index to assess the behavioural patterns of population groups. The aetiology of mandibular fractures varies with geographic location, population density, socio-economic status, culture, religion, temporal factors, as well as alcohol and substance involvement (Iida *et al.*, 2005; Chrcanovic, 2012; Ranchod & Morkel, 2014). Arranged in order of most to least common, aetiologies of mandibular fractures include interpersonal violence (IPV), road traffic accidents (RTA), sporting accidents, falls and work-related injuries (Ranchod & Morkel, 2014).

Globally, increased accessibility and acceptance of alcohol has brought about a significant increase in the frequency and complexity of mandibular fractures, especially in individuals from low socio-economic urban settings with escalating unemployment rates (Mathog *et al.*, 2000; Bowley *et al.*, 2004; McAllister, Jenner & Laverick, 2013; Porter, Lownie & Cleaton-Jones, 2013).

Alcohol abuse is a common denominator with IPV and RTA (Bowley *et al.*, 2004; Bormann *et al.*, 2009; Scolozzi, Martinez & Jaques, 2009; Desai, Lownie & Cleaton-Jones, 2010; Chrcanovic, 2012; O'Meara, Witherspoon & Hapangama, 2012). While 64-75% of South Africans presenting with mandibular fractures due to IPV are unemployed (Melmed & Koonin, 1975; Bola *et al.*, 2015), alcohol abuse is involved in 65% of these cases (Desai, Lownie & Cleaton-Jones, 2010). It is possible that these statistics fail to reflect the true burden alcohol has on fracture morbidity, especially when considering that in Dundee, Scotland alcohol consumption was responsible for a 115% increase in maxillofacial fractures between 1960 and 1977 alone (Adi, Ogden & Chisholm, 1990).

2.4.1.1. Alcohol abuse

Alcohol is a central nervous system depressant. Neuropsychologically, it inhibits the brain's control mechanisms, leading to impaired motor coordination and judgement (Bowley *et al.*, 2004; Pyungtanasup, 2008; Porter, Lownie & Cleaton-Jones, 2013). Alcohol also worsens fracture repair outcomes by increasing a patient's risk of requiring surgical intervention postoperatively (O'Meara, Witherspoon & Hapangama, 2012).

The systemic effects of alcohol includes suppression of T-cells, reduced osteocalcin secretion by osteoblasts and reduced collagen production (Mathog *et al*., 2000; Moore 2005). The resultant effects are a decreased bone volume and strength, an increased risk for successive infection, and prolonged wound healing.

2.4.1.1.1. Alcohol abuse, road traffic accidents and interpersonal violence

Unrestrained drivers sustaining facial injuries are four times more likely to be under the influence of alcohol (Shapiro *et al*., 2001; Pyungtanasup 2008), and may exceed the legal blood alcohol content (BAC) limit by more than three times (Bowley *et al*., 2004). Nevertheless, an emerging trend towards an increased frequency of violent mechanisms have been observed in both developed (Laski *et al.*, 2004; Ferreira, Amarante & Silva, 2005; Eggensperger, Smolka & Scheidegger, 2007) and developing countries (Adebayo, Ajike & Adekeye, 2003; Ansari, 2004; Porter, Lownie & Cleaton-Jones, 2013). The decreased incidence of RTA-related mandibular fractures is the result of stringent legislative changes and preventative measures involving seatbelt and airbags usage, as well as the reduction of the legal BAC limit in most countries (Andreuccetti *et al*., 2011).

2.4.1.2. Age and mandibular fracture aetiology

Mandibular fractures can occur at any age. Children are less prone to such fractures (Haug & Foss, 2000), as their cranial-to-facial ratio is approximately 8:1 - lower than the 2.5:1 ratio in adults (Zimmermann, Troulis & Kaban, 2005). This, coupled with unerupted teeth and underdeveloped paranasal sinuses, gives their mandibles and maxillae a greater tooth-to-bone ratio, making them more stable, flexible and resilient (Shaikh & Worrall, 2002; Gassner *et al.*, 2004; Zimmermann, Troulis & Kaban, 2005). In adolescents, the aforementioned structures are nearly fully developed coupled with increased interaction with the outside world (Shaikh & Worrall, 2002; Gassner *et al.*, 2004; Zimmermann, Troulis & Kaban, 2005), the prevalence of mandibular fractures in adolescents are comparable to that of their adult counterparts (Iida & Matsuya, 2002; Shaikh & Worrall, 2002).

Most RTA- and IPV-related mandibular fractures occur in people older than 18-years-of-age (Bamjee, Lownie & Cleaton-Jones, 1996) and the age group most affected by these mechanisms is 20-29-years-of-age (Ahmed *et al*., 2004; Simsek *et al*., 2007; Chrcanovic 2012). Falls are the most common mechanism of injury in individuals younger than 18-years-of-age (Qudah & Bataineh, 2002; Atilgan *et al.*, 2010) and between 40- and 80-years-of-age (Iida *et al*., 2003).

Despite the visible correlation between age of fracture presentation and mechanisms of injury, age of fracture presentation has no association with fracture sites, because the physics related to an injury mechanism influences the site of fracture occurrence to a larger degree when compared to inherent characteristics of the mandible (King, Scianna & Petruzzelli, 2004).

2.4.1.3. Sex and mandibular fracture aetiology

The most modal ratio for mandibular fractures between males and females is 3:1 (Subhashraj, Nandakumar & Ravindran, 2007; Scolozzi, Martinez & Jaques, 2009). This ratio is directly linked to a country's socio-cultural and economic value systems. In developed countries where women participate in social activities and are more susceptible to urban violence and RTAs, the male-to-female ratio in the adult population may be as low as 2,5:1 (Scolozzi, Martinez & Jaques, 2009). However, in countries such as the United Arab Emirates (Ahmed *et al.*, 2004), a male-to-female ratio as high as 11,7:1 has been observed. In South Africa, the ratio is 4:1 (Beaumont, Lownie & Cleaton-Jones, 1985; Mogajane & Mabongo, 2018).

2.4.1.4. Region-specificity of mechanism of injury.

The mandibular body is the most common fractured site, followed by the condyle, the angle and the symphysis (Ansari, 2004; Ferreira *et al.*, 2004; Martini *et al.*, 2006; Eggensperger, Smolka & Scheidegger, 2007; Roode, 2007). The mandibular body is the largest anatomical site in the mandible and is marked by the parasymphysis mesially and the mandibular angle laterally. Superiorly, the mandibular body is surmounted by the mid-canine to third molar. The mandibular body is commonly fractured during alcohol-related IPV (Torgersen & Tornes, 1992; Eggensperger, Smolka & Scheidegger, 2007; Mogajane & Mabongo, 2018) with a preponderance to the left side of the face since most people are right-handed (Busuito, Smith & Robertson, 1986; Park *et al.*, 2015).

In South Africa, conflicting findings have been reported regarding the most commonly fractured site and side of mandibular fractures. While some studies suggest that the most commonly fractured site is the mandibular angle (Desai, 2007; Mogajane & Mabongo, 2018), others (Beaumont, Lownie & Cleaton-Jones, 1985; Roode, 2007) indicate that the mandibular body is more commonly fractured. Fractures due to IPV in the South African population shows a preponderance to the right side of the mandible (Mogajane & Mabongo, 2018).

2.4.2. Fracture immobilisation

Fracture immobilisation refers to the anatomic re-approximation of bone fragments to establish and maintain preinjury occlusion and restore form and function (Ellis & Miles, 2007; Balaji, 2009). This should ideally be accomplished with the least morbidity and with the shortest recovery period (Koshy, Feldman & Chike-Obi, 2010; El-Anwar, El-Ahl & Amer, 2015). Optimal healing is achieved when fractured mandibular segments are adequately vascularized, immobilized, and properly aligned (Koshy, Feldman & Chike-Obi, 2010).

During mastication, the pulling action of muscles causes fractures of the anterior mandible to experience vertical and horizontal movements which results in shear and torsional stresses at the fractured site (Champy *et al.*, 1978; Sauerbier, Schön & Otten, 2008). On the other hand, mandibular angle fractures experience a vertical traction due to the actions of the temporalis, medial pterygoid and masseter. Fixation is aimed at nullifying the effects of muscle action on fractured sites.

Various fixation hardware schemes are available. One hardware scheme may be preferred over another depending on its costs and the fracture type and site that needs to be repaired. Prior to selecting a hardware scheme, considerations should be given to the quality of available bone, presence of infection and soft tissue disruption and the surgeon’s expertise (Gear *et al.*, 2005;

Koshy, Feldman & Chike-Obi, 2010). However, the principle deciding factor in selecting a hardware scheme, is the dental occlusal status (Koshy, Feldman & Chike-Obi, 2010). The most common hardware schemes employed, and approaches for hardware scheme insertion, are discussed below.

2.4.2.1. Closed reduction

Closed reduction, or indirect fixation, is the manipulation of fractured bone segments to establish anatomical reapproximation without surgically exposing the fracture. The most commonly employed form, namely maxillomandibular fixation (MMF) is described below.

2.4.2.1.1. Maxillomandibular fixation

The treatment of minimally-displaced closed fractures requires only the establishment and maintenance of pre-injury occlusion (Pyungtanasup, 2008; Scolozzi, Martinez & Jaques, 2009; Ellis, 2012). This can be achieved with MMF - securing wire or elastic bands between teeth of the mandibular and maxillary arches (Ellis & Miles, 2007). During this form of fixation, the skin and mucosae are not reflected and the integrity of the periosteum is preserved, thus encouraging bone healing. (Koshy, Feldman & Chike-Obi, 2010). This form of atraumatic fixation proves beneficial to geriatric patients, in which the periosteum is the only source of vasculature, as well as children, since it carries no risk of damaging developing teeth.

It is also indicated for open wounds and comminuted fractures since introduction of foreign materials in these instances increases the risk of infection (Balaji 2009); however, MMF provides non-rigid fixation which favours secondary bone healing via callous formation. Non-rigid fixation causes micromotion to occur between fractured bone segments which increases the likelihood of motion-induced osteolysis and inflammation.

In addition, MMF is a complex manoeuvre that lengthens operating time, carries risks of damage to dental papillae, oral mucosae, and has an 18% risk of blood-borne infection to the surgeon (Smartt *et al.*, 2005; Rai, Datarkar & Borle, 2011; Kumaresan & Ponnusami, 2014). Furthermore, the oral cavity is closed for 5-6 weeks (Koshy, Feldman & Chike-Obi, 2010), resulting in weight loss, poor oral hygiene, speech difficulties, limited jaw mobility, malocclusion, asymmetry and chronic pain (Haug & Foss, 2000; El-Anwar, El-Ahl & Amer, 2015). Post-operative admission is also required, which further inflates hospital costs and delays return to employment by the patient.

In the past, MMF was also used in concert with more rigid forms of fixation to maintain proper occlusion until internal fixation was achieved intraoperatively. However, a recent study (El-Anwar, 2018) compared surgical outcomes between MMF and manual MMF following treatment of parasymphyseal and body fractures, and reported no differences regarding dental occlusion and mouth opening 8 weeks post-surgery.

2.4.2.2. Open reduction and internal fixation

The main objective of fracture fixation is to achieve immediate restoration of form and function and undisturbed healing without the adjunctive use of MMF (Sauerbier, Schön & Otten, 2008; El-Anwar, 2018). Open reduction and internal fixation (ORIF), also known as osteosynthesis, is the process of reflecting the soft tissue surrounding a fracture, surgically exposing the fracture and using metal devices to bridge the fracture.

Hardware schemes used for internal fixation are classified into semi-rigid and rigid forms. All semi-rigid forms are load bearing, but rigid forms are further classified into load-bearing and load sharing subtypes based on the stability it provides a fracture.

Open reduction and internal fixation has become the mainstay for treating mandibular fractures (Ellis 2013). It is superior to closed reduction in that it allows for immediate pain-free oral opening, thus returning the patient's quality of life back to normal in a shorter period of time (Balaji 2009). While the benefits to the patient is clear, it harbours an increased morbidity (Ellis, 2010; Koshy, Feldman & Chike-Obi, 2010). This may be related to ORIF being employed to treat more severe fractures (Andreasen *et al*., 2008).

2.4.2.2.1. Approaches

The approach chosen to explore a fracture is based on the space required for the anchorage of a hardware scheme that can nullify force vectors acting across a fracture in a specific region of the mandible.

2.4.2.2.1.1. Extraoral approaches

Fractures in regions of the ramus, angle and subcondyle, including fractures in posterior and inferior aspects of the mandibular body, requires greater visualisation to ensure that the fracture has no gaping following fracture fixation. Fractures at these sites are therefore exposed via an extraoral approach (Hinds 1958; Mohan *et al*., 2012). Extraoral approaches results in facial scarring and carries a risks for injury to marginal mandibular nerves and cervical branches of the facial nerve (Devlin, Hislop & Carton, 2002; Sadhwani & Anchlia, 2013).

2.4.2.2.1.2. Intraoral approaches

Mandibular symphyseal and body fractures are accessed intraorally via a vestibular incision through the mucosa (Schön *et al.*, 2002; Koshy, Feldman & Chike-Obi, 2010). The incision may extend onto the external oblique ridge as high up as the mandibular occlusal plane, depending on the site that needs to be accessed. Intraoral approaches are deemed superior to extraoral approaches because of easier occlusal visualisation, improved aesthetic outcomes, time efficiency and can be performed under local anaesthesia with a minimal risk of facial nerve injury (Parmar *et al.*, 2014).

2.4.2.2.2. Semi-rigid fixation

Semi-rigid fixation involves the use of mono-cortical screws which engage the BCP, and bone plates with small dimensions (Balaji 2009; Singh *et al.,* 2012). Limited bone is required to buttress these screws because functional masticatory loads are shared between the bone plates and bone ends. This results in minimal interfragmentary and torsional movements and ensures functionally stability at the fractured site (Champy *et al.*, 1978; Koshy, Feldman & Chike-Obi, 2010; Ellis, 2013). The size of these hardware schemes allows for insertion via an intraoral approach.

2.4.2.2.2.1. Mini-plates

Mini-plates are pliable titanium plates with a profile of 0.9 - 1.0 mm x 6 mm and various standard lengths. All mini-plates accept 2.0 mm diameter screw with standard lengths ranging between length of 5 - 10 mm (Balaji 2009). Depending on their length, these plates may contain 2 to 6 holes for screw insertion, for example, a 2 cm long plate contains 4 holes.

Mini-plates are the most widely employed hardware scheme for treating non-displaced mandibular fractures (Michelet, Deymes & Dessus, 1973; Sauerbier, Schön & Otten, 2008). Champy and colleagues (1976) laid the scientific foundation for mini-plate placement on, what they referred to as ideal lines of osteosynthesis. These lines are located on biomechanically favourable regions of the mandible which experience less dynamic force vectors during masticatory function in fractured mandibles (Champy *et al.*, 1978; Koshy, Feldman & Chike-Obi, 2010). These lines comprise zones of tension and compression. The muscles of mastication cause tension in the alveolar aspect and compression in the basal aspect of fractures lateral to the MF. The application of a single mini-plate (Figure 2.1) on the tension zone is therefore sufficient to nullify forces vectors (Champy *et al.*, 1978). Fractures of the anterior mandible experience tension and torsion in response to muscle action. The insertion of two plates is therefore required to nullify these movements, with the inferior plate placed first to provide resistance to torsion (Sauerbier, Schön & Otten, 2008).

The size and pliability of these plates makes their placement less technique sensitive and shortens operating time, thus minimizing risks for infection and facial nerve paresis (Lazow & Tarlo, 2009). Despite this, a higher incidence of non-infectious wound dehiscence and plate exposure has been reported with mini-plate fixation compared to compression plates, particularly in sub-apically placed mini-plates (Ellis, 2011).

Figure 2.1: Healed interforaminal fracture treated with a mini-plate
(Source: Personal Collection McKay 2018)

2.4.2.2.3. Rigid fixation

Rigid fixation is the application of bulkier plates using more screws of a larger diameter (Figure 2.2) to provide absolute stability to fracture ends (Toma, Mathog & Toma, 2003; Koshy, Feldman & Chike-Obi, 2010). Rigid fixation permits primary, or direct, bone healing in the absence of callous formation via Harversian and direct osteonal remodelling (Koshy, Feldman

& Chike-Obi, 2010; Ellis, 2013). The application of rigid fixation is therefore ideal for instances where the bite force is great, such as in young healthy male patients, or in comminuted and multiple fractures which experience varied forces under functional loading. These plating systems prevents interfragmentary motion when functional masticatory forces are in effect and thus, motion-induced osteolysis (Balaji, 2009). Conversely, rigid internal fixation is technically demanding, because plates should be precisely adapted to bone (Kumar *et al*., 2015a). When the plate is not optimally adapted to the fractured bone segment, screw loosening and subsequently malunion, non-union or malocclusion of fracture segments may result.

2.4.2.2.3.1. Locking reconstruction plates

Reconstruction plates are the primary structural buttress of comminuted fractures, continuity defects or atrophied bone (Ellis & Graham, 2002). They are manufactured in three different plate thicknesses and various lengths but accepting the same 10 mm x 2.0-mm diameter screws, for example, six-hole reconstruction plates are straight and have a 2.0 mm x 4.7 mm x 70 mm profile. Thicker and longer plate profiles accommodate the distribution of forces across a larger area, hence, preventing screw loosening.

These plates are manufactured in locking and non-locking forms. The locking form is the only hardware scheme that bear all masticatory loads by countering shear forces and converting them to compressive forces at the fracture site (Parmar *et al*., 2014). The screws contain threads under their heads which lock into that of the plate as well as locking onto the bone (Ellis & Graham, 2002). There is no need for precise plate contouring and the construct functions as an internal-external fixator. Because the plate is not directly screwed to bone, it carries a reduced risk for malocclusion secondary to ineffective plate contouring (Haug, Street & Goltz, 2002). To add, this construct reduces interference of the blood supply, thus allowing the periosteum to regrow below the plate (Gardner, Helfet & Lorich, 2004).

In addition, tightening of plates to bone, which decreases physiologic loading onto bone, resulting in bone loss, is circumvented. This, together with the low risks for screw loosening, decreases the risk for post-operative inflammatory complications and necrosis propagated by an inflammatory response (Ellis & Graham, 2002). Furthermore, the forces acting on the bone during mandibular function does not cross the fracture area. Instead, it moves from one bone segment to the plate via the screws, to the other bone segments, and *vice versa* (Ellis & Graham, 2002). In addition, fractures treated with these plates do not require two-point fixation because the plate creates compression in the superior border of the mandibular fracture (Scolozzi, Martinez & Jaques, 2009). This proves beneficial in especially atrophic and edentulous mandibles, where there is not only limited space for the insertion of two plates, but where an inverse relationship between mandibular height and the rate of infection and fibrous non-union following fracture fixation, has been documented (Ellis & Price, 2008). Despite this, there are no differences in the rate of union, fibrous union, malunion or non-union, overall failure or infection between outcomes for the Champy technique and locking titanium plates. Additionally, the mini-plates require shorter operative placement time (Bouloux, 2010).

Figure 2.2: Rigid fixation with recon plates following pathological bone resection

(Source: Personal Collection McKay 2018)

2.5. BONY LANDMARKS OF THE NEUROVASCULAR BUNDLE

Interforaminal fractures are managed with great caution, because the mental nerve, artery and vein contained within the MF provides sensation and blood supply to mucous membranes and skin in the angle of mouth to the labial region (Toh *et al.*, 1992; Koshy, Feldman & Chike-Obi, 2010). Special consideration should also be given to the markedly thinner BCP in the premolar dento-alveolar region (Ellis, 2012) as well as the smaller distance between tooth root apices and the inferior border of the mandible, resulting from the greater space taken up by tooth roots (Koshy, Feldman & Chike-Obi, 2010). Variations of the neurovasculature in this region are of particular concern and bony landmarks indicative of such variations are described below.

2.5.1. Course of the mandibular canal

The IAN is housed within the MC and is the most commonly injured branch of the trigeminal nerve (Juodzbalys, Wang & Sabalys, 2010). Iatrogenic injury to the IAN may manifest as a variety of neurosensory alterations which includes transient to permanent anaesthesia, paraesthesia or dysthesia of the lower lip and chin. At birth, the MC is in close proximity to the lower border of the mandible. However, in mandibles of geriatric edentulous individuals, resorption causes the MC to be in close proximity to the alveolar border (Srinivas Moogala *et al.*, 2014).

According to Worthington, (2004) three different MC curvatures are encountered, namely: 1) a progressive increased curvature from mesial to lateral regions of the mandible; 2) a steep ascent from mesial to lateral regions and 3) a catenary-like canal which resembles a curve formed by a cable under its own weight. When applying this classification to cone beam computed tomography (CBCT) scans of 156 patients, investigators (Mirbeigi, Kazemipoor &

Khojastepour, 2016) observed all canal types in the same proportions, with most of them (80%) being bifid lateral to the third molar. When repeating the analysis on panoramic radiography, a non-significant difference ($p = 0.37$) was reported regarding the visualization of the different canal curvatures; however, bifid canals were observed in only 7.4% of the sample.

2.5.2. Mental foramen

Precise knowledge on variations of the MF is vital to dental surgical procedures performed in the mandibular premolar region.

2.5.1.2.2. Position of the mental foramen

Tebo and Telford (1950) first described the MF in line with longitudinal axes of teeth. The position of the MF may vary from the canine to the first molar. It is commonly located between the first and second premolar (Fishel *et al.*, 1976; Berry, Bannister & Standring, 2000) in European populations, but varies for non-European populations (Tebo & Telford, 1950; Berge & Bergman, 2001). The MF is most commonly located below second premolar in Indians (44.08% - 73.2%) (Sankar, Bhanu & Susan, 2011; Siddiqui *et al.*, 2011; Budhiraja *et al.*, 2013; Udhaya, Saraladevi & Sridhar, 2013) and Bosnians (50.3%) (Voljevica, Talović & Hasanović, 2015).

2.5.2.2. Location and size of the mental foramen

At birth, the MF opens below and between the sockets of the two deciduous premolars near the lower border of the mandible. It is located midway between upper and lower borders in the young adult; however, in the geriatric edentulous mandible, resorption causes the MF to be in proximity to the alveolar ridge (Tallgren 1972; Srinivas Moogala *et al.*, 2014).

Various studies (Siddiqui *et al.*, 2011; Udhaya, Saraladevi & Sridhar, 2013; Voljevica, Talović & Hasanović, 2015) assessed the location of the MF using dry bone morphometric analysis. Kalender (2012) observed significant differences between males and females for the horizontal and vertical diameter of the MF. They also reported significant differences between partially edentulous and dentate mandibles for the distance from the anterior crest to the superior border of the MF.

2.5.1.2.3. Accessory mental foramina

Accessory mental foramina (AMF) is a variation that presents when the IAN bifurcates before the embryonic formation of the MF. It has been a focus of much investigation due to the implications accessory mental nerves may have on achieving an effective mental nerve block (Pancer *et al.*, 2014; Ravi *et al.*, 2017), as well as improving outcomes for various surgical procedures (Iwanaga *et al.*, 2015; Rahpeyma & Khajehahmadi, 2018). The prevalence, amount, size and location of AMF have been described previously. These vary widely between population groups (Chu, Nahas & Martino, 2014; Paraskevas, Mavrodi & Natsis, 2014; Srinivas Moogala *et al.*, 2014; Iwanaga *et al.*, 2015; Voljevica, Talović & Hasanović, 2015).

2.6. IMAGING MODALITIES

Preoperative planning of mandibular fracture treatment includes elucidating the BCP thickness in the region of the fracture and the distance from the outer buccal cortex to vital structures. These include tooth root apices, the IAN, the position of the MF and neurovascular variations such as the presence of AMF (Kalender, Orhan & Aksoy, 2012; Al-Jandan *et al.*, 2013; Cassetta *et al.*, 2013b; Paraskevas, Mavrodi & Natsis, 2014; Talaat *et al.*, 2015). Knowledge of these structures allows the surgeon to assess ideal location for fracture fixation (Al-Jandan *et al.*, 2013).

Various imaging modalities may be used as part of the perioperative planning of mandibular fracture fixation including intraoral - and extraoral radiography, CBCT and computed tomography (CT). Large discrepancies on a single sample may be observed between imaging modalities when quantifying variations (Fuakami *et al.*, 2011; Muinelo-Lorenzo *et al.*, 2015; Mirbeigi, Kazemipoor & Khojastepour, 2016). It is therefore crucial that a surgeon weighs the benefits to risks when selecting an imaging modality.

2.6.1 Panoramic radiography

Identification of the roots of teeth, the course of the IAN as well as the location of the MF relative to teeth, will ultimately assist in plate positioning for fracture fixation (Koshy, Feldman & Chike-Obi, 2010). Panoramic radiography is a useful screening tool for visualizing these structures. However, visualisation of AMF with this 2-dimensional screening tool is poor as the size of these foramina are generally less than 1.0 mm (Toh *et al*,. 1992). Neves and colleagues (2011) assessed the AMF prevalence using both CBCT and panoramic radiography on 127 mandibles and observed a lower prevalence in panoramic radiographs (1.2%) compared to CBCT (7.2%). Incorrectly performed panoramic radiographs also demonstrate significant differences with dry bone measurements (Bou Serhal *et al.*, 2002; Bahlis *et al.*, 2010). In addition, buccolingual width cannot be determined with this imaging modality and assessment of bifid MCs cannot be properly visualized on most traditional radiographs (Mirbeigi, Kazemipoor & Khojastepour, 2016).

2.6.2. Cone-beam computed tomography

Cone-beam computed tomography (CBCT) has improved pre-operative planning of dental surgery (Cassetta *et al.*, 2013b). It provides improved visualization of clinically significant three-dimensional structures when compared to panoramic radiography (Katakami *et al.*, 2008;

Al-Jandan *et al.*, 2013). This is due to its ability to provide data in the sagittal, coronal, axial and panoramic planes (da Silva Ramos, Capelozza & Rubira-Bullen, 2011). Its increased accuracy and fast image acquisition, enables surgeons to conduct measurements of the structures prior to surgery based on the patient's anatomy (Estrela *et al.*, 2008; Ganz, 2011; Kumar *et al.*, 2015b).

The x-ray beam that rotates around the stationary patient, results in fewer movement artefacts (Dawood, Patel & Brown, 2009). Furthermore, its radiation exposure dosage is ten times less than that of conventional CT scans (Kumar *et al*., 2015b), which can be further reduced when selecting an X-ray with a smaller field of view (Dawood, Patel & Brown, 2009; Pauwels *et al.*, 2012). To add, It is more cost efficient compared to CT scans (Cassetta *et al*., 2013b; Kumar *et al*., 2015b) and has a good grey density range, spatial resolution, contrast and pixel/noise ratio (Cassetta *et al*., 2013b).

On the other hand, obtaining CBCT images with high resolution, requires an increased radiation dosage when compared to 2-dimensional imaging modalities (Cotton *et al.*, 2007; Shukla *et al.*, 2015). This increases the risk of carcinogenesis and damage to radiosensitive tissues such as salivary and thyroid glands (Pauwels *et al*., 2012). Furthermore, CBCT is also prone to artefacts caused by dental metallic posts which creates distortion because of differential absorption (Haridas *et al*., 2016).

This literature curation emphasizes the need for population specific data on interforaminal region variations of the mandible, with the potential to enhance surgical management of fractures.

CHAPTER THREE: RESEARCH DESIGN

3.1. RESEARCH QUESTION

- Do ancestry and sex influence morphological variations in the interforaminal region of the mandible?
- Do age and tooth loss influence such variations?
- Can population specific information be applied to facilitate clinical decision-making of mandibular fracture repair?

3.1. AIMS

3.1.1. To assess variations in the interforaminal region of the mandible between sex and ancestral subgroups

3.1.2. To evaluate the influence of tooth loss and age on variations between sex and ancestry subgroups

3.1.3. To apply population-specific information for mini-plate placement

3.2. OBJECTIVES

3.2.1. Observe and record:

3.2.1.1. the number and distribution of teeth in hemi-mandibles

3.2.1.2. the positions of the mental foramen in line with longitudinal axes of tooth roots of hemi-mandibles containing teeth in the interforaminal region

3.2.2. Measure:

3.2.2.1. the size and distance of the mental foramen relative to borders of each hemi-mandible

3.2.2.2. the distance and location of accessory mental foramina

3.2.2.3. the buccal cortical plate and buccal bone thickness

3.2.2.4. the inferosuperior and anteroposterior location of the mandibular canal

3.2.3. Observe and record overlap between possible mini-plate placement locations and:

3.2.3.1. teeth

3.2.3.2. the mandibular canal

3.2.3.3. accessory mental foramina

3.3. HYPOTHESES

H_0: Ancestry, sex, age and dentition do not influence mandibular morphological variations

H_a: Ancestry, sex, age and dentition do influence mandibular morphological variations

CHAPTER FOUR: MATERIALS AND METHODS

4.1. ETHICAL APPROVAL

Approval for this study was obtained from the Human Research Ethics Committee, Faculty of Medicine and Health Science, Stellenbosch University under the ethics reference number SU-1810 on 29/03/2018. Consent to use human cadaveric materials for research/teaching purposes was obtained following a protocol set by the University of Stellenbosch's division of Anatomy and Histology. Consent to use these materials for health research was obtained from the study participants while alive or from the Western Cape Inspector of Anatomy.

4.2. MATERIALS AND METHODS

Mandibles were resected from cadavers with known ancestry, sex and age. The mandibles were macerated and left to dry following the removal of residual soft tissue. In the event of a hemi-mandible presenting visible pathology, ante-mortem fractures or perimortem fractures, the contralateral hemi-mandible was included in this investigation. The sample comprised mandibles with varying dentition. The number and distribution of teeth, including the sex, ancestry and age was recorded for each mandible. The perimortem loss of a tooth, as indicated by a preserved alveolar margin, was considered as tooth presence.

4.2.1. External morphology

This section describes the influence of age and dentition on external interforaminal variations within and between subgroups.

4.2.1.1. Position of mental foramina in longitudinal axes of teeth

Each mandible was placed on an even surface with maximal contact to its inferior border.

In hemi-mandibles containing dentition in the interforaminal region, a dissection needle was placed across the vertical midpoint of the MF to observe the tooth associated with the MF (Figure 4.1).

Figure 4.1: The positions of the MF in longitudinal axes of teeth. (PI) Between longitudinal axes of the canine and first premolar teeth, (PII) on the longitudinal axis of the first premolar tooth, (PIII) between longitudinal axes of the first and second premolar teeth, (PIV) on the longitudinal axis of the second premolar tooth, (PV) between longitudinal axes of the second premolar and first molar teeth, (PVI) on the longitudinal axis of the first molar tooth.

4.2.1.2. Location of the mental foramen

A Digital Vernier Calliper was used to assess the location and size of the MF, bilaterally relative to the borders of the mandible (Figure 4.2).

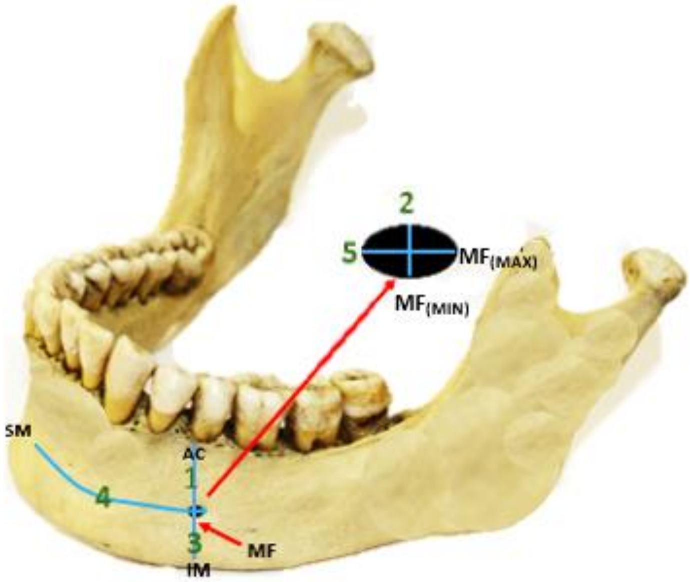

Figure 4.2: The location and size of the mental foramen. Parameter 1: Anterior crest to superior border of MF; parameter 2: minimum diameter of the MF ($MF_{(MIN)}$); parameter 3: inferior mandibular border to inferior MF border (MF-IM); parameter 4 - symphysis menti to mesial border of MF (SM-MF) and parameter 5 - maximum diameter of MF ($MF_{(MAX)}$)**.**

4.2.1.3. Accessory mental foramen location

In hemi-mandibles presenting the appearance of an AMF, a solution of 25% ammonia was mixed with rubber latex liquid in a 3:1 ratio. Food colouring was added to the mixture to aid visualisation. The mixture was injected into the MC using 23-gauge needles to infiltrate the canal. This verified continuity with the MC. When the mixture was seen protruding through MFs and AMFs, glacial acetic acid was used to stall the solution. Once the solution was dry, parameters 6 and 7 were measured (Figure 4.3). These parameter values were used to determine coordinates for the vertical and horizontal location of the AMF relative to the MF using Pythagorean equations. The location of AMF was used to assess the risk for injury to accessory mental nerves during screw insertion for fracture repair.

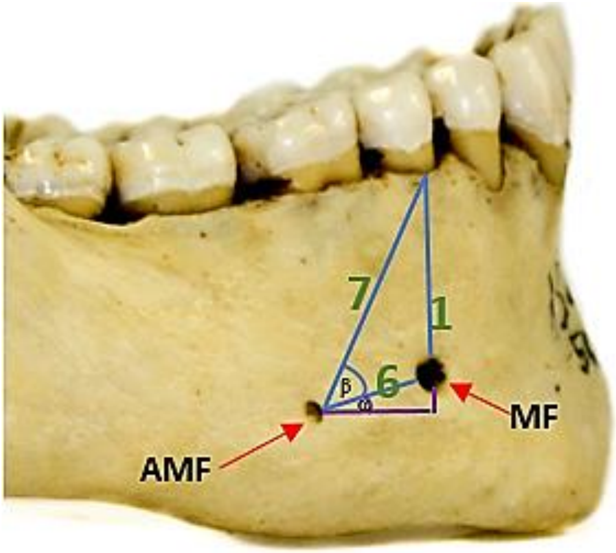

Figure 4.3: Location of accessory mental foramina relative to mental foramina. The coordinates of the AMF location relative to the MF was determined using Pythagoras and is indicated with by the purple lines. (Parameter 6) distance from MF to AMF, (Parameter 7) distance from AMF to the anterior crest. (AMF) accessory mental foramina, (MF) mental foramina

(Source: Personal Collection McKay 2018)

4.2.2. Internal morphology

An adaptation of the method described by de Souza Fernandez *et al*.(2010a) was employed to investigate the internal morphology in the interforaminal region of the mandible. On the external surface of each hemi-mandible, three horizontal planes were drawn in the interforaminal region (Figure 4.4a) using a pencil marker. The first crossed the horizontal midpoint of the MF (denoted F). The other planes were drawn 3 mm superior (denoted S) and inferior to the foraminal midpoint (denoted I). On the foraminal horizontal plane, two consecutive points, each measuring 4.5 mm from one another, were made both anteriorly and posteriorly to the foraminal midpoint. These points were extended orthogonally through superior and inferior horizontal planes to establish four vertical planes. Where the horizontal and vertical planes bisect, 12 points were identified on each hemi-mandible - four on each of the three horizontal planes (Figure 4.4b).

The horizontal planes indicate possible locations for mini-plate placement, while the four points on each of the three horizontal planes indicate where screws are inserted through mini-plates to bridge fractured bone segments.

Three horizontal planes were also drawn on the lingual aspect of the mandible and corresponded with the location of the three planes on the buccal aspect of each hemi-mandible. A Dremel® 4000 hand drill with 0.75 mm x 38 mm Dremel® metal cutting discs was used to section the bone para-sagittally through each of the four vertical planes so that each hemi-mandible contained five bone segments (Figure 4.4b). Assessments of the internal morphology were conducted from bone segments two and four (Figure 4.5).

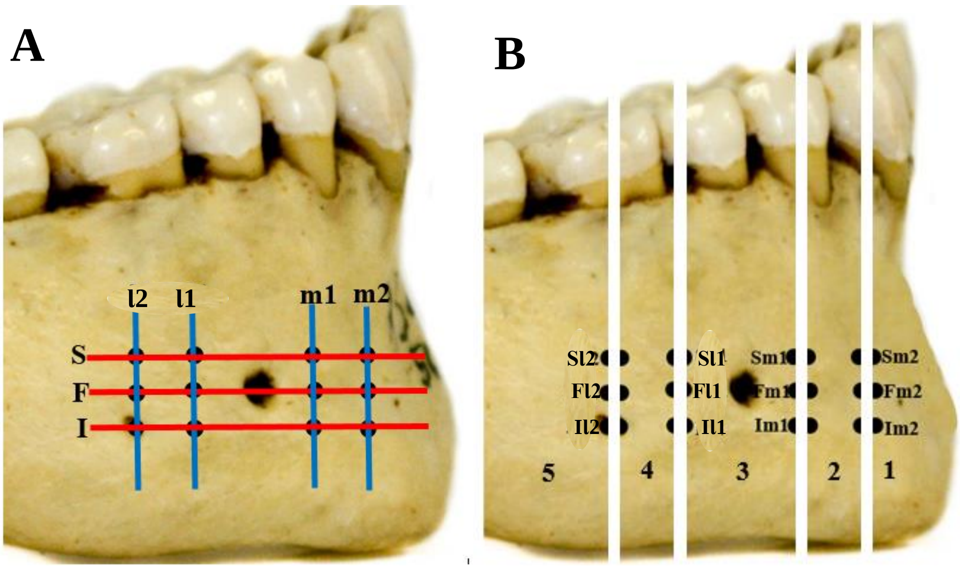

Figure 4.4: Points for internal morphology assessment. A) The red lines indicate horizontal planes, while blue lines indicate vertical planes, B) Black dots indicate reference points for assessments of internal morphological variations. Each dot on each of the horizontal planes demarcates the location where a screw can be inserted through a mini-plate to bridge a fracture in the intermorainal region. (S) horizontal plane 3 mm superior to the horizontal foraminal plane, (F) horizontal plane through the horizontal foraminal midpoint, (I) horizontal plane 3 mm inferior to the foraminal horizontal plane, (m1) 4.5 mm mesial to the foraminal midpoint, (m2) 9 mm mesial to the foraminal midpoint, (l1) 4.5 mm lateral to the foraminal midpoint, (l2) 9 mm lateral to the foraminal midpoint.

On each aspect of bone segments two and four, three transverse planes were established by joining horizontal planes on buccal and lingual aspects using a pencil marker. The BCP thickness was measured from all three transverse planes at each site (Figure 4.5a). The vertical distance from the superior transverse plane to the superior border of the MC was measured at site l1 and l2 of bone segment 4 to determine the inferosuperior location of the MCs (Figure 4.5b). These measurements were also conducted at site m1 and m2 on bone segment two where canals, assumed to be anterior loops (AL), were present. The buccal bone thickness was obtained by measuring the combined buccal cortical plate and buccal cancellous bone anterior to MCs and ALs. It was used to determine the anteroposterior location of these canals. At assessments points where MCs and ALs had association with foraminal and inferior transverse planes, (Figure 4.5c) the buccal bone thickness was measured on the transverse plane of interest.

In mandibles where more than one assessment point on the superior transverse plane had association with the roots of teeth, the minimum buccal bone (MBB) thickness at one of the four assessment points on this plane was selected for further analysis. This was done to determine the predicted risk of injury to teeth and the MC with screws of different lengths at at least one site during mini-plate placement. Similarly, on foraminal and inferior transverse planes, the MBB thickness was selected where MCs had association with either of the planes at more than one study point. The MBB thickness on each plane was assigned into a category according to thickness and the cumulative frequency of the various categories on each transverse plane was used to determine the risks for iatrogenic injury to structures at each transverse plane.

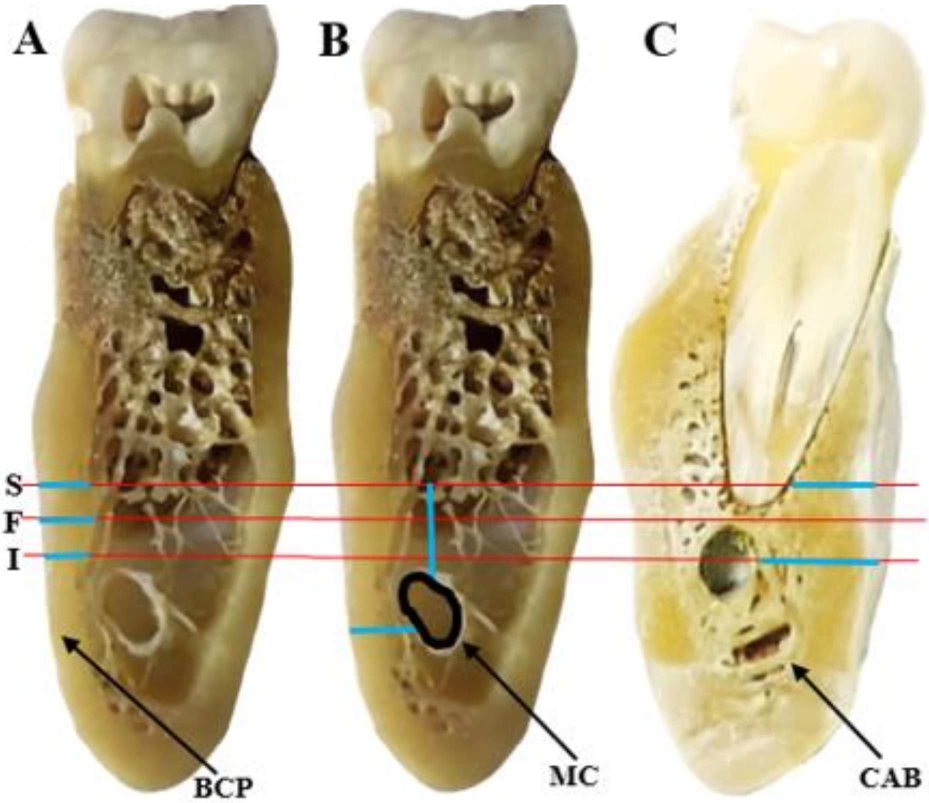

Figure 4.5: Parameters measured on mesial and lateral aspects of bone segments two and four. Red lines indicate transverse planes formed by the superior, foraminal and inferior horizontal planes cross-sectioning the mandible. A) The blue lines indicate buccal cortical plate on each transverse plane. B) The blue lines indicate the distance from the mesial border of the mandibular canal to the outer buccal cortical plate (BCP-MC) and from the superior transverse plane to the superior border of the mandibular canal (S-MC). C) The blue lines indicate the buccal bone thickness anterior to the roots of teeth and the mandibular canal. (S) transverse plane 3 mm superior to the foraminal midpoint, (F) transverse plane through the foraminal midpoint, (I) transverse plane 3 mm below the foraminal midpoint s (BCP) buccal cortical plate, (CAB) cancellous bone, (MC) mandibular canal

4.3. STATISTICAL ANALYSIS

For statistical analysis, a biostatistician, Mrs. Tonya Esterhuizen at the Centre for Evidence-Based Health Care, Division of Epidemiology and Biostatistics, Faculty of Medicine and Health Science, Stellenbosch University, was consulted. The data was analysed using IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA). Descriptive statistics were performed on measurements. Mean values and standard deviations (in mm) was calculated at a 95% confidence interval and a p-value < 0.05 wasconsidered statistically significant.

The Independent sample t-test compares the means of two independent groups (test variable) to determine a significant difference between associated populations (grouping variable). This test was selected to compare parameter means between sexes within the same ancestral group. Similar to the independent sample t-test, the one-way analysis of variance (ANOVA) test determines statistically significant differences between the means of three or more independent groups (test variable) by testing the null hypothesis that the means between groups are equal. A significant difference exists between means of at least two independent groups in the comparison when the null hypothesis is rejected at $p < .050$. This test was therefore used to determine ancestral differences between subgroups of the same sex. A Tukey post hoc-test was performed to determine which groups in the comparison differed where significant differences were reported during an ANOVA.

A paired sample t-tests is used to investigate whether the mean difference between two sets of observations is 0. A significant difference exists when $p < 0.05$. This test was conducted to determine significant differences between observations at two sites.

A Pearson's correlation (r) indicates the direction and strength of a linear relationship between two metric variables. Values range between -1 and 1, where 0 indicates no relationship between variables, 1 indicates a strong relationship. This test was conducted to investigate possible associations between age and parameter readings. Similarly, a Spearman's correlation (r_s) indicates the relationship between variables, however, this test is conducted for ordinal variables. Henceforth, the influence of the number of teeth on parameter values was investigated using this correlation.

The influence of individual teeth on parameter values was investigated using a Mann Whitney U test. This test places parameter readings in order of size and assigns a number to each parameter reading according to its magnitude (e.g. smallest reading gets the number 1). The data is split into two independent groups (test variable) and the mean of the assigned numbers is calculated for each group. The test identifies whether the mean ranks differ significantly between independent groups.

Pearson's chi-square tests were employed to investigate sex differences between groups for categorical data (observations). This test assumes that observed differences between at least two independent samples arose by chance. A p-value $< .050$ indicates a statistically significant difference between subgroups. This test was also conducted to investigate ancestral differences in the distribution of categorical data.

A two-way mixed effect intraclass correlation coefficient (ICC) and a Cohen's Kappa statistic (K) was used as a measure of agreement between measurements and observations repeated by the primary investigator (intra-rater) on 24 randomly selected hemi-mandibles, respectively. These are reliability indices which expresses the agreement beyond chance as a value between

0 and 1. An ICC value less than 0.5 is indicative of poor reliability, a value between 0.5 and 0.75 indicates moderate agreement, a value between 0.75 and 0.9 indicates good agreement and a value greater than 0.9 indicates excellent agreement. On the other hand, Kappa values less than 0.2 indicates poor agreement, values between 0.21 and 0.4 indicates fair agreement, values between 0.41 and 0.6 indicates moderate, values between 0.61 and 0.8 indicate substantial agreement and values greater than 0.81 indicates almost perfect agreement. Reliability testing was repeated by a second observer (inter-rater) on an independent sample of the same magnitude using the same tests.

CHAPTER FIVE: RESULTS

Two hundred and thirty-five hemi-mandibles of SAB, SAC and SAW males and females met the inclusion criteria. South African Black and SAW female subgroups contained only 7 and 15 of hemi-mandibles, respectively. Hemi-mandibles from these subgroups were excluded from further investigation due to a low power for significance testing. The cohort (N=213) comprised hemi-mandibles of 4 ancestry and sex subgroups, namely SAC females, SAC males, SAB males and SAW males. The mean age of the cohort was 49.89±13.44 years (Table 5.1). The male-to-female ratio was 2.8:1 and the third molar was the most common absent tooth, especially in SAW males (Table 5.2).

Table 5.1: Cohort age distribution. The SAW male subgroup had the highest mean age

	SAC Female	**SAC Male**	**SAW Male**	**SAB Male**	**Cohort**
Minimum age	25	20	35	29	20
Maximum age	89	78	91	57	91
Mean ±SD	45.38±14.96	46.54±11.37	68.05±13.93	42.85±8.31	49.89±13.44

(SAC) South African Coloured, (SAW) South African White, (SAB) South African Black

Table 5.2: Cohort demographics and distribution of teeth. The proportion of each tooth present per subgroup is indicated in brackets

	SAC Female	SAC Male	SAW Male	SAB Male	Cohort
Right					
N	28	45	20	14	107
third molar	12 (42.86%)	16 (35.55%)	5 (25%)	7 (50%)	40 (37.38%)
second molar	15 (53.57%)	17 (37.77%)	5 (25%)	9 (64.29%)	46 (32.99%)
first molar	14 (50%)	16 (35.55%)	6 (30%)	9 (64.29%)	45 (42.06%)
second premolar	19 (67.86%)	18 (40%)	7 (35%)	11 (78.57%)	55 (51.40%)
first premolar	22 (78.57%)	29 (64.44%)	10 (50%)	13 (92.86%)	74 (69.16%)
Canine	22 (78.57%)	32 (71.11%)	12 (60%)	11 (78.57%)	88 (82.24%)
second incisor	22 (78.57%)	30 (66.66%)	10 (50%)	13 (92.86%)	75 (70.09%)
first incisor	22 (78.57%)	28 (62.22%)	11 (55%)	13 (92.86%)	74 (69.16%)
Left					
n	28	46	19	13	106
third molar	10 (35.71%)	15 (32.61%)	1 (5.26%)	6 (46.15%)	32 (30.19%)
second molar	14 (50%)	18 (39.13%)	5 (26.32%)	10 (76.92%)	47 (44.34%)
first molar	15 (53.57%)	16 (34.78%)	6 (31.58%)	8 (61.54%)	45 (42.45%)
second premolar	19 (67.86%)	21 (45.65%)	8 (42.11%)	11 (84.62%)	59 (55.66%)
first premolar	21 (75%)	31 (67.39%)	9 (47.37%)	11 (84.62%)	72 (67.92%)
Canine	23 (82.14%)	33 (71.74%)	10 (52.63%)	13 (100%)	79 (74.53%)
second incisor	23 (82.14%)	30 (65.22%)	10 (52.63%)	11 (84.62%)	74 (69.81%)
first incisor	23 (82.14%)	29 (63.04%)	9 (47.37%)	12 (92.31%)	73 (68.87%)

The number of hemi-mandibles in each subgroup is represented by n. The proportion of hemi-mandibles containing a particular tooth is indicated in brackets. (SAC) South African Coloured, (SAW) South African White, (SAB) South African Black

5.2. EXTERNAL MORPHOLOGY

This section describes the influence of age and dentition on the location of the MF, the positions of the MF in longitudinal axes of teeth and the location of AMF in relation to the MF for each subgroup. Comparisons are made between SAC males and females, as well as between SAB, SAC and SAW males, where applicable.

5.2.1. The positions of the MF in longitudinal axes of teeth

The position of the MF was determined in 79 right (72.95%) and 80 left (73.08%) hemi-mandibles, as these hemi-mandibles contained teeth in the interforaminal region. There were no significant differences between subgroups regarding the MF position ($p > .050$). The MF was most commonly located between longitudinal axes of the first and second premolar teeth (Figure 5.1). Good to perfect intra-rater repeatability ($K = .730 - 1; p < .001$) was achieved. Fair and substantial agreement was achieved during inter-observer reliability tests on right ($K = .320, p = .100$) and left ($K = .710; p <.001$) hemi-mandibles regarding the positions of the MF in the longitudinal axes of teeth *(See addendum B; Table 2).*

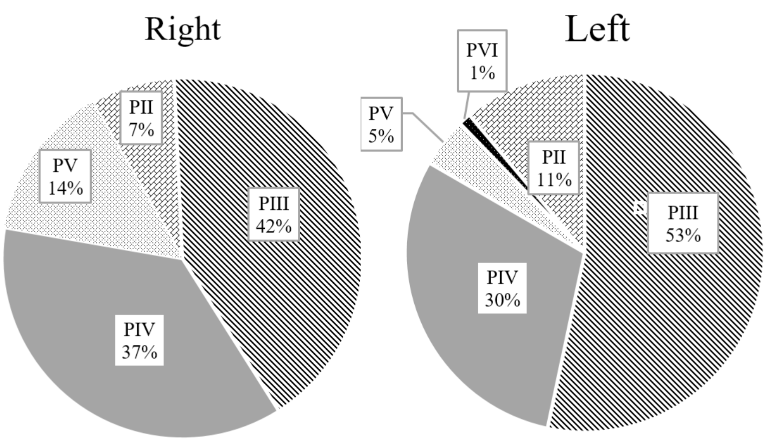

Figure 5.1: A schematic representation of the frequency of the positions of mental foramina in line with longitudinal axes of teeth. The most common position of the MF was between longitudinal axes of the first and second premolar teeth. (PI) Between longitudinal axes of the canine and first premolar teeth, (PII) on the longitudinal axis of the first premolar tooth, (PIII) between longitudinal axes of the first and second premolar teeth, (PIV) on the longitudinal axis of the second premolar tooth, (PV) between longitudinal axes of the second premolar and first molar teeth, (PVI) on the longitudinal axis of the first molar tooth

5.2.2. Location and size of the mental foramen

A significant difference was observed between SAC males and females for the distance from the inferior border of the MF to the inferior border of the mandible (MF-IM) on right ($p < .001$) and left ($p = .001$) hemi-mandibles (Table 5.3).

Significant differences were also observed between SAB and SAC males for the distance from the symphysis menti to the mesial border of the MF (SM-MF) in right hemi-mandibles ($p = .008$). Dentition (Figure 5.2) and age (Figure 5.3) influenced select parameters, with no differences between subgroups ($p > .005$). Good to excellent for intra-rater agreement was achieved ($p < .050$; $r = .770 - .9\ 70$). Inter-rater reliability was good to excellent for 8 of 10 bilateral measurements *(See addendum B; Table 3).*

Table 5.3: The location and size of the mental foramen. Parameter MF-IM was greater in SAC males when compared to females on left and right hemi-mandibles and SAC males had a markedly smaller SM-MF on right hemi-mandibles when compared to SAB males. Data (in mm) is expressed as mean ± standard deviation (SD).

	SAC Female	SAC Male	SAW Male	SAB Male	Cohort
Right					
AC-MF	13.92 ± 3.74	13.83 ± 4.19	13.17 ± 4.25	15.69 ± 3.06	13.97 ± 3.97
$MF_{(MIN)}$	2.11 ± 0.50	2.29 ± 0.56	2.39 ± 0.46	2.66 ± 0.73	2.31 ± 0.57
MF-IM	12.21 ± 0.97^{a}	13.91 ± 1.92^{b}	14.17 ± 1.32	14.38 ± 1.79	13.57 ± 1.78
SM-MF	25.54 ± 2.06	25.73 ± 2.42^{c}	26.33 ± 2.21	27.94 ± 2.26^{d}	26.08 ± 2.37
$MF_{(MAX)}$	3.34 ± 0.97	3.30 ± 1.25	3.34 ± 0.79	3.70 ± 1.34	3.37 ± 1.10
Left					
AC-MF	13.59 ± 3.64	13.43 ± 3.90	13.39 ± 3.67	14.61 ± 2.93	13.61 ± 3.66
$MF_{(MIN)}$	2.86 ± 2.61	2.37 ± 1.00	2.43 ± 0.57	2.29 ± 0.47	2.50 ± 1.52
MF-IM	12.56 ± 1.37^{a}	14.08 ± 1.94^{b}	14.03 ± 1.3	14.78 ± 2.93	13.76 ± 1.85
SM-MF	25.74 ± 2.15	26.31 ± 2.87	27.61 ± 2.91	27.50 ± 2.26	26.54 ± 2.69
$MF_{(MAX)}$	3.20 ± 0.87	3.16 ± 1.15	3.53 ± 0.97	3.24 ± 1.06	3.24 ± 1.03

Differing letter a and b indicate significant differences between SAC males and females. Differing letter c and d indicate significant differences between two male subgroups. Significance was defined at $p < .050$. (AC-MF) Anterior crest to superior border of the MF; ($MF_{(MIN)}$) minimum diameter of the MF, (MF-IM) inferior border of the mandible to the inferior border of the MF, (SM-MF) symphysis menti to anterior border of the MF, ($MF_{(MAX)}$) maximum diameter of the MF. (SAC) South African Coloured, (SAW) South African White, (SAB) South African Black

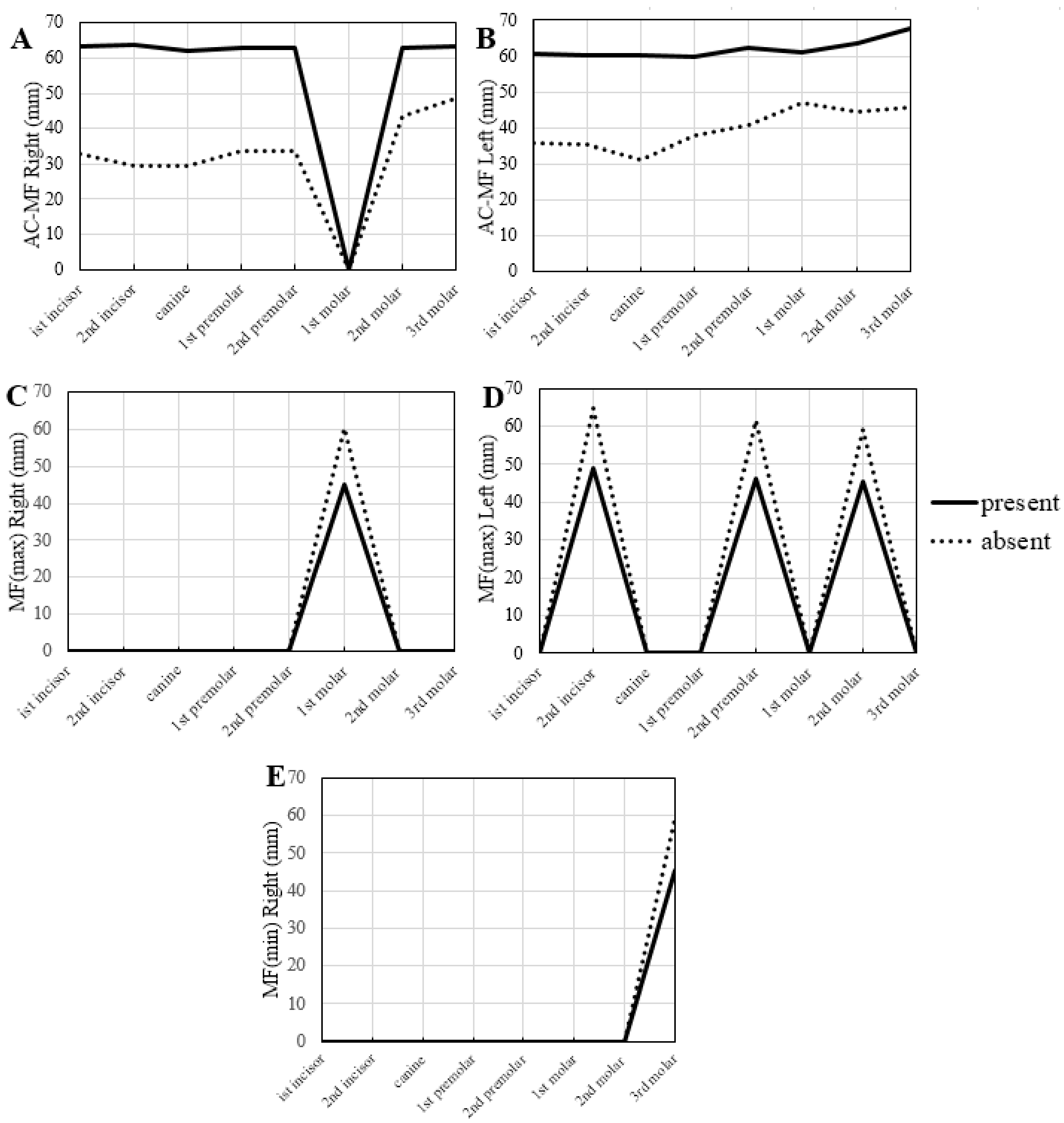

Figure 5.2: The influence of dentition on the location and size of the mental foramen. The graphs indicate significant differences between the mean ranks of parameters in mandibles where a tooth was present and the mean rank of parameters in mandibles where a tooth was lost. A) The presence of each tooth, excluding the first molar on right hemi-mandibles, was associated with a higher reading for AC-MF on right ($0 < p \leq .015$) hemi-mandibles. B) The presence of each tooth was associated with a higher reading for AC-MF on left ($0 < p \leq .020$) hemi-mandibles. C) On right hemi-mandibles, the presence of first molars were associated with a significantly smaller $MF_{(MAX)}$ (p = *.013*). D Parameter $MF_{(MAX)}$ of left hemi-mandibles was smaller with the presence of second incisors (p = *.022*), second premolars (p = *.009*) and second molars (p = *.021*). E) The presence of second molars was associated with associated with a smaller reading for $MF_{(MIN)}$ (p = *.028*).

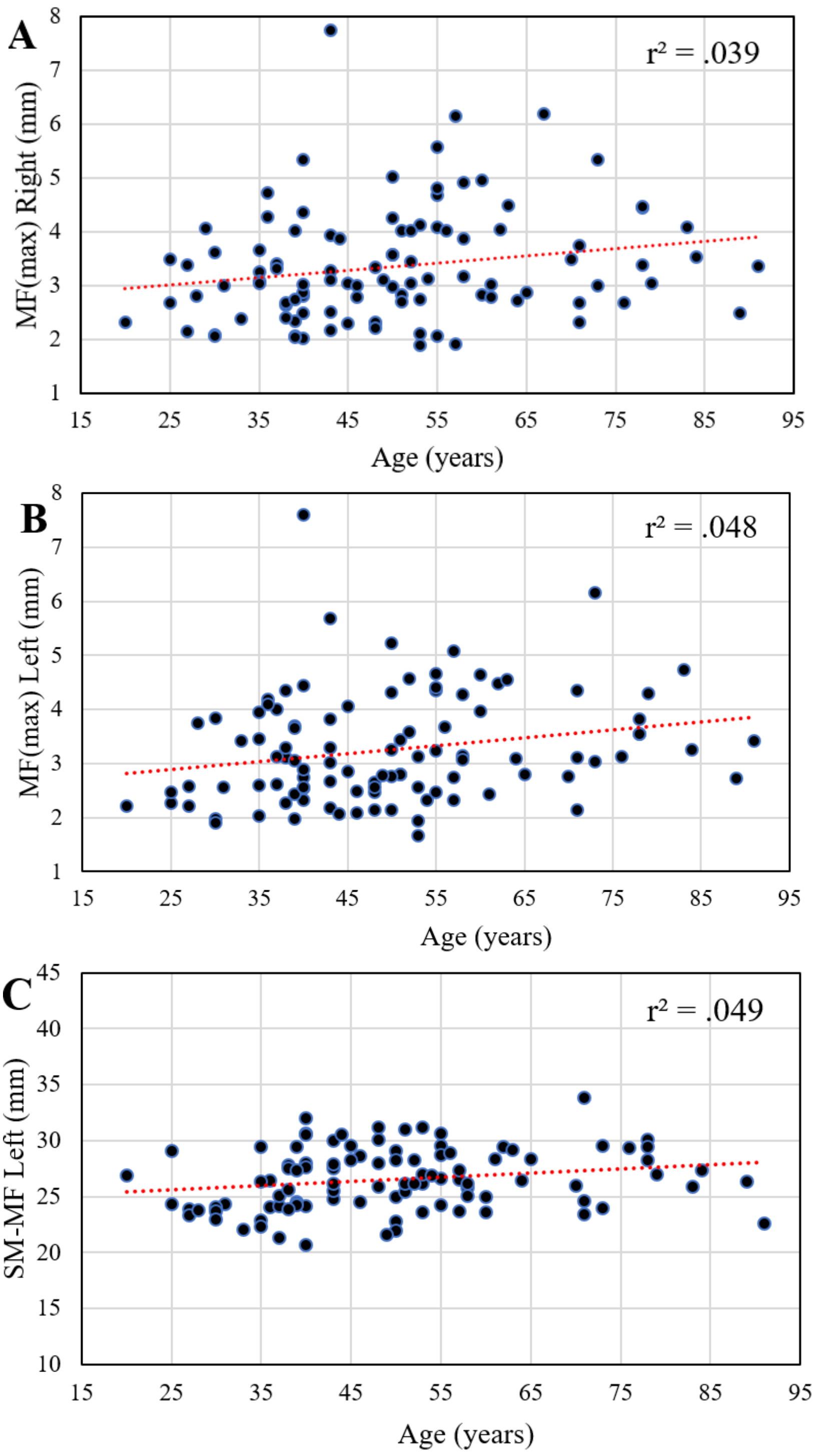

Figure 5.3: The influence of age on the location and size of the mental foramen. A) $MF_{(max)}$ showed a weak associations with age on right (*p = .048*) hemi-mandibles, B) $MF_{(max)}$ showed a weak associations with age on left (*p = .046*) hemi-mandibles, C) Left sided hemi-mandibles had a weak positive relationship with age for parameter SM-MF (*p = .033*). The coefficient of determination (r^2) indicates the strength of the association, with 0 indicating no association and 1 indicating a strong association

5.2.3. Accessory mental foramina.

A single accessory mental AMF was observed in seven right (6.54%) and seven left (6.60%) hemi-mandibles (Figure 5.4). Seven AMF were found in the SAC male subgroup (3.29%). SAC female hemi-mandibles contained 4 AMF (1.88%) and SAW male hemi-mandibles contained 3 AMF (1.41%). Two right hemi-mandibles of SAC males contained an additional AMF. The majority (50%) of AMF were located mesial and superior to the MF. The subgroup-specific prevalence of single AMF indicated an even distribution with 7.69% for SAC males, 7.14% for SAC females and 7.69% for SAW males.

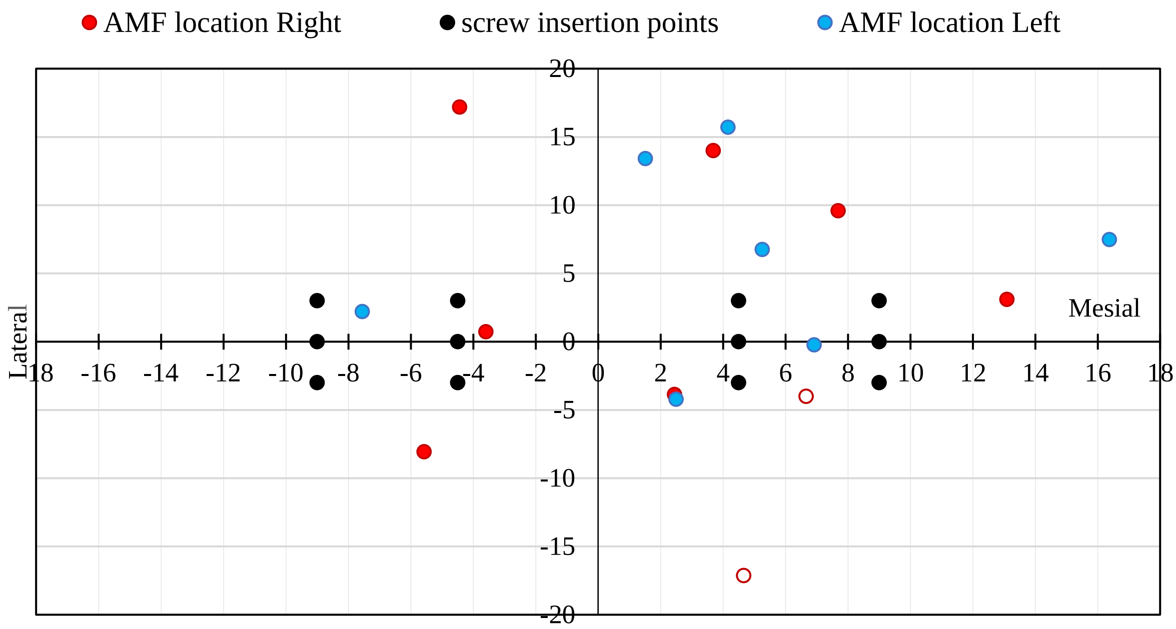

Figure 5.4: Location of accessory mental foramina relative to mental foramina. The origin of the graph represents the midpoint of the MF. A total of 50% of accessory mental foramina were located mesial and superior to the MF. Double AMF are indicated by red circles. (AMF) accessory mental foramina

5.3. INTERNAL MORPHOLOGY

This section describes the influence of age and dentition on internal interforaminal variations within and between subgroups.

5.3.1. Buccal cortical plate thickness

The results on BCP thickness (Table 5.4) revealed no significant differences between subgroups at any assessment points on the superior transverse plane ($p > .050$). On the foraminal transverse plane of right hemi-mandibles, the BCP in SAC males was greater than SAC females at Fm2 ($p = .018$) while the BCP was significantly thicker in SAB males compared to SAW males at Fl2 ($p = .049$). On the inferior transverse plane of right hemi-mandibles, SAB ($p = .025$) males and SAC males (p = .018) had a greater BCP compared to SAW males at Im1, while SAC males had a greater BCP compared to SAW males ($p = .043$) and SAB males ($p = .043$) at Il2. On the foraminal transverse plane of left hemi-mandibles, BCP was greater in SAB males compared to SAW males at Fm1 ($p = .018$) and Fm2 ($p = .015$). South African Coloured males also had a greater BCP compared to SAC females at Fm2 ($p = .038$) and Fl2 ($p = .016$). On the inferior transverse plane of left hemi-mandibles, SAB males had a thicker BCP compared to SAC males at Im2 ($p = .022$), while SAC males had a thicker BCP compared to SAC females (p = .016) and SAW males at Il1 ($p = .045$). Inter-rater reliability for BCP was substantial to perfect at all assessment points (0.8 < r < 1), while intra-rater reliability was almost perfect (.900 < r < 1) *(see addendum B; Table 4).*

Table 5.4: Buccal cortical plate thickness (mm). Data is expressed as mean ±SD

	SAC Female	SAC Male	SAW Male	SAB Male	Cohort
Right					
Sm1	1.96 ± 0.64	1.93 ± 0.62	1.93 ± 0.67	2.29 ± 0.66	1.99 ± 0.64
Sm2	1.88 ± 0.57	2.03 ± 0.64	1.92 ± 0.52	2.35 ± 0.45	2.01 ± 0.59
Sl1	2.10 ± ±0.97	2.39 ± 0.75	2.15 ± 0.62	2.50 ± 0.55	2.28 ± 0.78
Sl2	2.18 ± 0.90	2.40 ± 0.80	2.42 ± 1.70	2.64 ± 0.64	2.38 ± 1.03
Fm1	1.89 ± 0.58	2.10 ± 0.58	1.78 ± 0.49	2.22 ± 0.48	2.00 ± 0.56
Fm2	1.99 ± 0.60[a]	2.18 ± 0.74[b]	1.77 ± 0.45	2.25 ± 0.55	2.06 ± 0.65
Fl1	2.08 ± 0.67	2.50 ± 0.75	2.21 ± 0.63	2.73 ± 0.86	2.36 ± 0.75
Fl2	2.18 ± 0.74	2.50 ± 0.80	2.03 ± 0.52[c]	2.55 ± 0.62[d]	2.33 ± 0.74
Im1	2.05 ± 0.49	2.21 ± 0.45[c]	1.83 ± 0.52[d]	2.26 ± 0.40[c]	2.11 ± 0.49
Im2	2.15 ± 0.57	2.26 ± 2.21	2.09 ± 0.59	2.15 ± 0.54	2.19 ± 0.57
Il1	2.24 ± 0.60	2.50 ± 0.69	2.21 ± 0.43	2.36 ± 0.59	2.35 ± 0.74
Il2	2.23 ± 0.52	2.53 ± 0.89[c]	2.00 ± 0.43[d]	2.48 ± 0.77[d]	2.30 ± 0.74
Left					
Sm1	2.13 ± 0.74	2.14 ± 0.76	1.97 ± 0.61	2.36 ± 0.44	2.13 ± 0.96
Sm2	1.90 ± 0.61	2.05 ± 0.60	1.38 ± 0.51	2.30 ± 0.36	2.00 ± 0.57
Sl1	2.11 ± 0.68	2.12 ± 0.71	2.22 ± 0.72	2.27 ± 0.61	2.16 ± 0.68
Sl2	2.14 ± 0.65	2.21 ± 0.86	2.53 ± 0.83	2.69 ± 0.77	2.31 ± 0.81
Fm1	1.85 ± 0.58	2.13 ± 0.64	1.79 ± 0.54[c]	2.39 ± 0.39[d]	2.03 ± 0.61
Fm2	1.87 ± 0.56[a]	1.96 ± 0.55[b]	1.68 ± 0.41[c]	2.19 ± 0.36[d]	1.91 ± 0.52
Fl1	1.98 ± 0.63	2.35 ± 0.77	2.04 ± 0.52	2.42 ± 0.47	2.20 ± 0.61
Fl2	2.10 ± 0.51[a]	2.51 ± 0.79[b]	2.30 ± 0.64	2.52 ± 0.58	2.36 ± 0.69
Im1	2.15 ± 0.67	2.21 ± 0.63	1.88 ± 0.32	2.18 ± 0.37	2.13 ± 0.58
Im2	2.13 ± 0.55	2.14 ± 0.47[c]	1.80 ± 0.48	2.25 ± 0.38[d]	2.09 ± 0.50
Il1	2.01 ± 0.55[a]	2.36 ± 0.62[bc]	1.95 ± 0.51[d]	2.44 ± 0.68	2.20 ± 0.61
Il2	2.14 ± 0.53	2.44 ± 0.68	2.06 ± 0.47	2.29 ± 0.71	2.27 ± 0.62

Differing letter a and b indicate significant differences between SAC males and females. Differing letters c and d indicate significant differences between two male subgroups, while similar letters indicate no significant difference. Significance was defined at $p < .050$. (S) plane 3 mm superior to the foraminal plane, (F) plane bisecting the horizontal foraminal midpoint, (I) plane 3 mm inferior to the foraminal plane, (m2) 9 mm mesial to the foraminal midpoint, (m1) 4.5 mm mesial to the foraminal midpoint, (l1) 4.5 mm lateral to the foraminal midpoint, (l2) 9 mm lateral to the foraminal midpoint. (SAC) South African Coloured, (SAW) South African White, (SAB) South African Black

The influence of dentition and age on BCP (Figure 5.5) did not differ between subgroups ($p > .050$). In the cohort, BCP showed a weak positive correlation ($\leq .228\ r_s \leq .390;\ p < 0.05$) with the number of teeth at all points except at assessment points lateral to the foraminal midpoint on foraminal and inferior planes ($p > 0.05$) of right hemi-mandibles. BCP showed a negative weak association with age at Sm1 (p = .018; r = -.234), Sm2 ($p = .013;\ r = -.245$), Fm1 ($p = .015;\ r = -.240$), Fm2 ($p = .001;\ r = -.329$), Im1 ($p = .003;\ r = -.295$) and Fl2 ($p = .018,\ r = .-234$). Left hemi-mandibles showed weak positive correlations at all points ($p < 0.05;\ \leq .193\ r_s \leq .248$), excluding Fl2 and Il2 ($p > 0.05$). Weak associations with age was observed at Sm1 ($p = .0.31;\ r = -.215$) and Il1 ($p = .045;\ r = -.200$). No significant differences regarding the influence of dentition and age were observed between subgroups ($p > .050$)

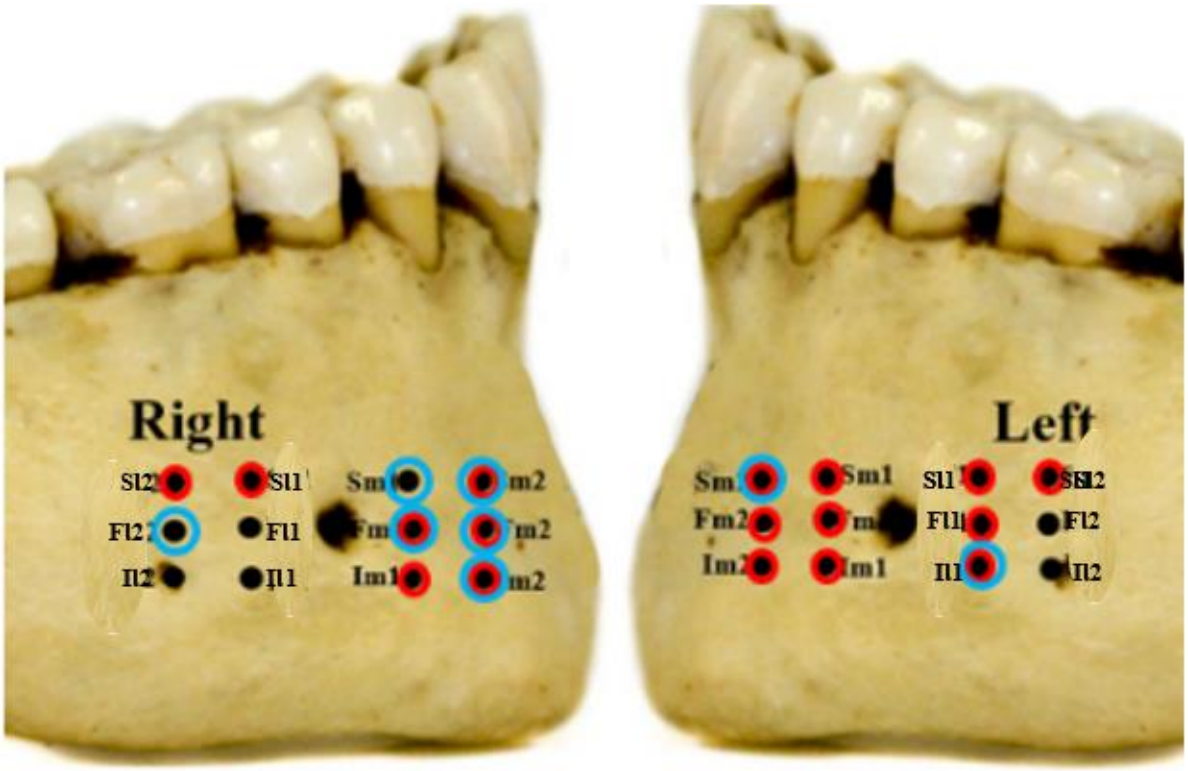

Figure 5.5: The influence of dentition and age on buccal cortical plate thickness. A weak positive relationship was observed between the number of teeth and the buccal cortical plate thickness at sites indicated by red circles, while a negative weak relationship was observed between age and buccal cortical plate thickness at sites indicated by blue circles. Dentition influenced buccal cortical plate thickness at most sites, while the effects of age was prominent at mesial assessment points of right hemi-mandibles

5.3.2. Location of anterior loops and mandibular canals

Anterior loops (AL) were observed in 18 right (16.82%) and 16 (15.09%) left hemi-mandibles at site m1. Mandibular canals (MC) were observed in all (100%) of right and left hemi-mandibles. The anteroposterior and inferosuperior location of ALs and MCs did not differ between SAB males, SAC males and SAW males at any sites ($p > .050$). Age and degree of tooth loss had no association with the anteroposterior and inferosuperior location of canals of right or left hemi-mandibles (p > .050) at any sites. These variables were therefore not considered during further analyses.

At site l1 of left hemi-mandibles, the distance between the superior transverse plane and superior border of MCs was not only greater ($p = .049$) in SAC males (Figure 5.6B), but the buccal bone was also thinner when compared to SAC females ($p = .013$) (Figure 5.6D). South African Coloured males also had a larger buccal bone thickness anterior to MCs (Figure 5.6C) at l1 ($p = .010$) and l2 ($p = .013$) on right hemi-mandibles (*See Addendum D, table 7*). Overall, canals were in close association with the inferior transverse plane, suggest that mini-plate fixation on this plane poses a risk for iatrogenic injury to the inferior alveolar nerve, depending on the bone quantity on this plane. Bone was also thicker at lateral assessment points, suggesting a lower risk for injury to the IAN at these points.

The BCP showed substantial to perfect ($.800 < r < 1; p < .050$) inter-rater agreement at 23 of 24 assessment points, while almost perfect agreement was achieved ($.900 < r < 1; p < .001$) in 23 of 24 assessment points during inter-rater reliability testing *(see addendum B; Table 5).*

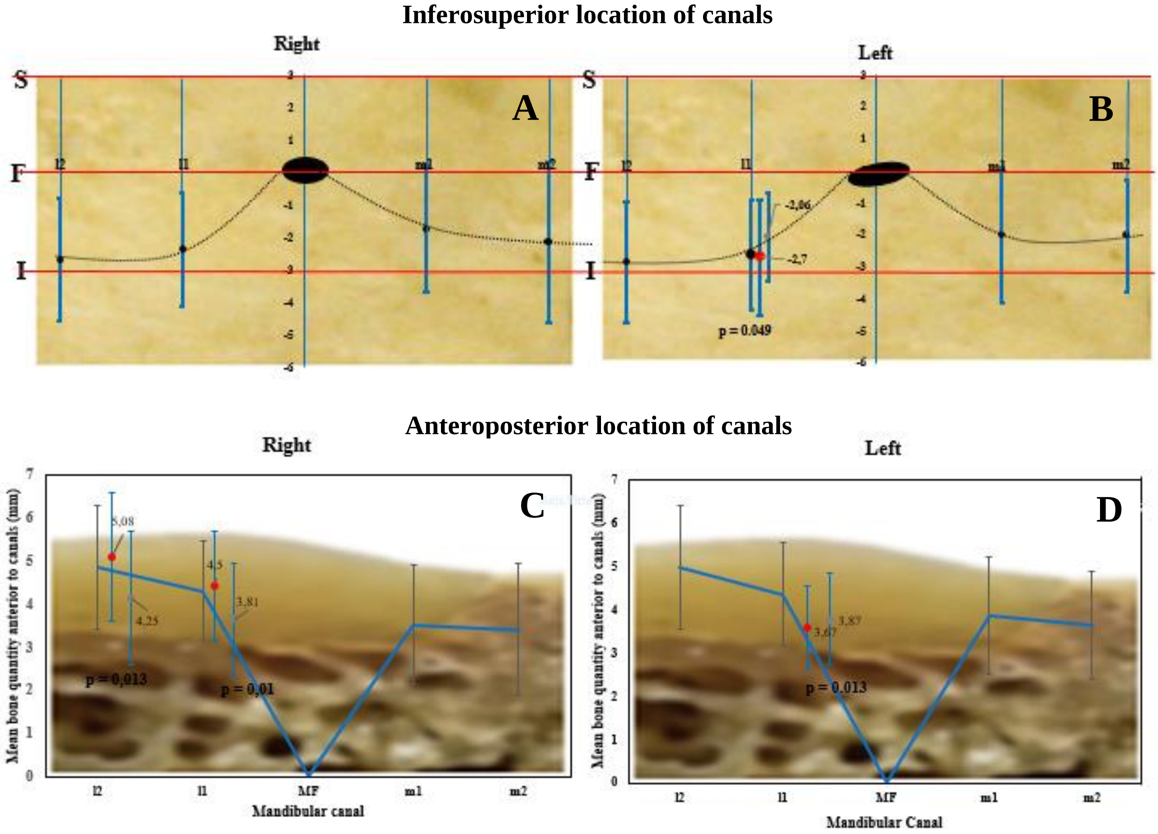

Figure 5.6: Inferosuperior and anteroposterior location of canals mesial and lateral to the mental foramen. The figure illustrates differences between SAC males (red) and females (grey)in relation to cohort means. Canals were lower in males when compared to females at I1 of left hemi-mandibles. Bone was also thicker at right lateral assessment points of SAC male hemi-mandibles when compared to SAC females. (SAC) South African Coloured.

5.3.4. Minimum buccal bone thickness

As previously described, 66.36% right and 75.47% left hemi-mandibles had dentition in the interforaminal region. At least a single assessment point on the superior transverse plane had association with teeth in 21 right and 12 left of hemi-mandibles. Anterior loops were associated with the foraminal transverse plane in 3 right (2.80%) and 3 left (2.83%) hemi-mandibles at Fm1. On the inferior transverse plane, 7 right (6.53%) and 7 left (6.59%) ALs were associated with assessment point Im1. Sixteen (14.95%) right and 9 (8.49%) left MCs had associations with foraminal transverse planes, respectively, while 37 and (34.58%) right and 48 (45.28%) left canals were associated with the inferior plane.

Left hemi-mandibles of SAC females had a greater MBB compared to SAC males (*p = 0.46*) on the inferior transverse plane (Table 5.5). The MBB thickness was greater on the foraminal plane when compared to the superior (*p = .007*) and inferior planes (*p = .001*) of right hemi-mandibles. The MBB of left hemi-mandibles was also thicker on the foraminal transverse plane when compared to superior (*p = .004*) and inferior transverse planes (*p = .001*).

Table 5.5: The mean minimum buccal bone thickness. The MBB was greatest on the foraminal plane.

Transverse plane	SAC Female	SAC Male	SAW Male	SAB Male	Cohort
Right					
Superior	6.15 ± 2.53	5.88 ± 2.85	6.72 ± 2.78	6.48 ± 1.97	5.97 ± 2.76^{d}
Foraminal	7.02 ± 2.67	7.16 ± 2.03	6.67 ± 2.52	6.61 ± 1.84	6.69 ± 2.04^{c}
Inferior	6.17 ± 1.63	6.17 ± 2.01	5.70 ± 1.89	5.23 ± 1.76	5.84 ± 1.90^{d}
Left					
Superior	5.61 ± 2.82	5.91 ± 2.84	7.07 ± 2.07	5.45 ± 2.95	6.23 ± 2.58^{d}
Foraminal	7.04 ± 1.51	6.84 ± 2.13	7.00 ± 1.78	6.05 ± 2.27	6.91 ± 2.08^{c}
Inferior	6.29 ± 2.38^{a}	5.98 ± 1.75^{b}	5.76 ± 1.98	5.48 ± 1.85	5.83 ± 1.90^{d}

Differing letter a and b indicate differences between SAC males and females. Differing letters c and d indicate differences between transverse planes, while similar letters indicate no differences. (SAC) South African Coloured, (SAW) South African White, (SAB) South African Black.

5.3.4.1. Risk for iatrogenic injury

The predicted risk for iatrogenic injuries with standard screws of different lengths used in concert with a standard 1 mm thick mini-plates, is illustrated below (Figure 5.7). When compared to foraminal and inferior planes, 4 mm screws carry a higher risk for iatrogenic injury to tooth roots on the superior plane. These risks remain almost constant bilaterally, even for screws with larger lengths, but are more pronounced in right hemi-mandibles. Four to eight mm screws are associated with an almost steady increased risk for injury to structures on the inferior plane, but reaches a plateau for screw lengths greater than 8 mm. The comparative increase in left hemi-mandibles are associated with a thinner mean MBB in male subgroups. The foraminal transverse plane has the lowest risks for inadvertent injuries to vital structures, increasing from 1.9 to below 7.55% for screw lengths 4 – 8 mm, bilaterally. While risks increase slightly for screws of larger lengths on left hemi-mandibles, risks for injury is almost double for screws greater than 8 mm in length for right hemi-mandibles.

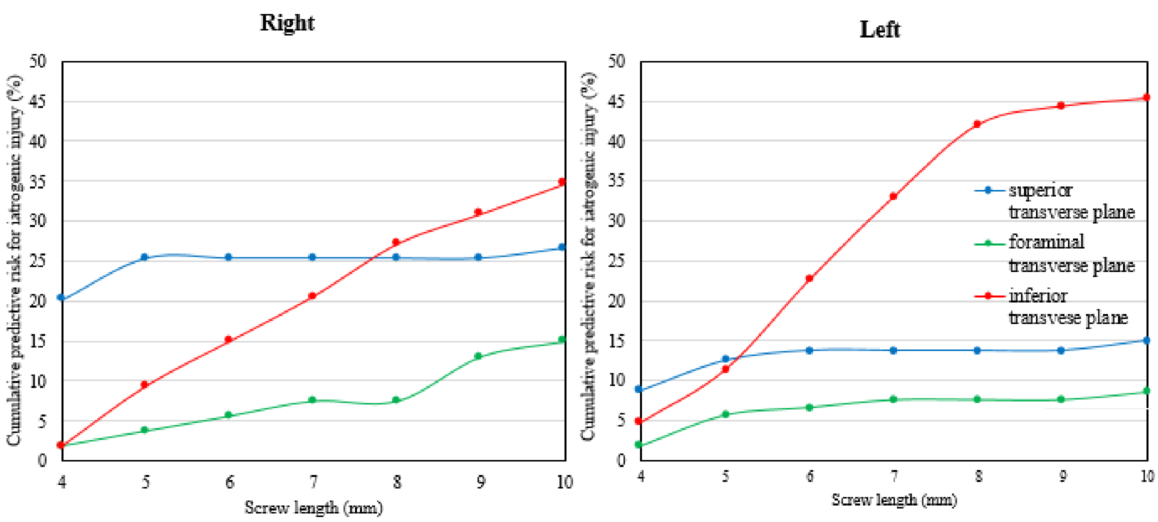

Figure 5.7: Predicted risks for iatrogenic injury. The foraminal transverse plane had the lowest risks for inadvertent injuries to vital structures, which increases from 1.9 to below 8% for screw lengths 4 – 8 mm, bilaterally.

CHAPTER SIX: DISCUSSION

Dry bone morphometric analysis is a cost-effective means of obtaining population-specific information on variations in the interforaminal region (McKay, Tchokonte-Nana & Mbajiorgu, 2018; Paraskevas, Mavrodi & Natsis, 2014). The mandibles used in this investigation is representative of the population served by state hospitals in the Western Cape, given the shared socio-economic status between individuals attending state hospitals and the cadavers from which mandibles were retrieved. However, the mean age of the cohort (49.89 ± 13.44) does not reflect the age demographics of individuals presenting with mandibular fractures (Ahmed *et al.*, 2004; Simsek *et al.*, 2007; Chrcanovic 2012).

The location of the MF is commonly described in relation to the longitudinal axes of teeth because this information can easily be applied in a clinical setting (Budhiraja *et al.*, 2013; Paraskevas, Mavrodi & Natsis, 2014; Laher & Wells, 2016). Similar to other investigations, the MFs in our cohort was most commonly located between longitudinal axes of the first and second premolar teeth (Berge & Bergman, 2001; Chu, Nahas & Martino, 2014). Various studies have reported MFs in line with the longitudinal axis of the second premolar tooth as the most common position (Sankar, Bhanu & Susan, 2011; Siddiqui *et al.*, 2011; Budhiraja *et al.*, 2013; Udhaya, Saraladevi & Sridhar, 2013; Voljevica, Talović & Hasanović, 2015). This position was the second most common in the current investigation. Likewise, an AMF may also impede surgical procedures depending on its location (Kalender, Orhan & Aksoy, 2012; Rahpeyma & Khajehahmadi, 2018). The 6.57% prevalence of a single AMF in this investigation is in agreement with findings in Japanese (Naitoh *et al.*, 2009; Katakami *et al.*, 2008) and Turkish (Kalender, Orhan & Aksoy, 2012) population groups. However, this finding is discrepant to a previous investigation on South Africans, indicating a 21.38% prevalence of a single AMF (McKay, Tchokonte-Nana & Mbajiorgu, 2018).

This disparity could partly be explained by differences in the definition applied. Previous morphometric analyses on dry hemi-mandibles considered all buccal foramina as AMF (McKay, Tchokonte-Nana & Mbajiorgu, 2018; Singh & Srivastav, 2010) contrary to the current study, which only classified foramina as AMFs once continuity with the MC could be established. The location of AMF relative to the MF varies between populations groups and may be located predominantly mesial and inferior (Katakami *et al.*, 2008)**,** lateral and superior (Naitoh *et al*., 2009; Neves *et al*., 2014) and superior to the MF (Imada & Fernandes, 2012). Our results revealed that 50% of foramina in this investigation were located mesial and superior to the MF. Similar findings on this AMF location have been reported for South Indians (Rajkohila *et al.*, 2018). These differences illustrate the importance of considering anatomical variations, in the approach to mandibular fracture repair.

The MF location and size have also been described in relation to borders of the mandible (Sankar, Bhanu & Susan, 2011; Siddiqui *et al.*, 2011; Voljevica, Talović & Hasanović, 2015)**.** Results from the current investigation reveal that the distance from the inferior border of the MF to the inferior border of the mandible (MF-IM) was larger in SAC males when compared bilaterally to SAC females. These results concur with other studies reporting on sex differences in this parameter (Kalender, Orhan & Aksoy, 2012; Laher & Wells, 2016), and can be ascribed to an overall larger mandible in males (Kharoshah, Almadani & Ghaleb, 2010).

Variations in the morphology of the mandible have also been ascribed to ancestry-related dentition patterns (Schwartz-Dabney & Dechow, 2003; Hanihara & Ishida, 2005; Katranji, Misch & Wang, 2007; Oettlé, 2014). Our results demonstrate a greater distance from the symphysis menti to the anterior border of the MF (SM-MF) on right hemi-mandibles of SAB males when compared to SAC males; however, the findings of this investigation showed no ancestral differences regarding the influence of teeth on mandibular form. The asymmetry of this finding could be linked to a higher bite force in the habitual chewing side of SAB male mandibles compared to SAC males (Harris & Clark, 2008; Santana-Mora *et al.*, 2013).

In our cohort, the absence of each mandibular tooth, excluding the first molar of right hemi-mandibles, was associated with a smaller distance from the anterior crest to the anterior border of the MF (AC-MF). Similarly, results by (Oettlé 2014) showed that the vertical height of the mandible in the region of the MF is negatively influenced by tooth loss. Our results revealed that the loss of first and third molars in right hemi-mandibles were associated with an increased maximum diameter ($MF_{\mathbf{(MAX)}}$) and minimum diameter of the MF ($MF_{\mathbf{(MIN)}}$), respectively. On the other hand, loss of second incisors, second premolars and second molars in left hemi-mandibles were associated with a greater $MF_{\mathbf{(MAX)}}$. The asymmetry regarding the influence of tooth loss on the size of the MF could be related to a reduction in the occlusal contacts which form when the cusp of a maxillary tooth interdigitates with the groove of a corresponding mandibular tooth (Jang, Kim & Chun, 2012). These would differ between right and left hemi-mandibles in mandibles with a habitual chewing side (Santana-Mora *et al.*, 2013). Similar to the influence of tooth loss, the influence of age on external morphology did not differ between subgroups and was associated with an increased SM-MF on left hemi-mandibles, and $MF_{\mathbf{(MAX)}}$ bilaterally. This implies that $MF_{\mathbf{(MAX)}}$ becomes larger with advanced age, more so in mandibles with a greater degree of tooth loss.

External adaptations of a bone's shape in response to changes in masticatory and occlusal loads are coupled with internal adaptations (Frost, 1983; Wolf, 1986; Nicholson & Harvati, 2006; Humphries, 2007; Ogawa & Osato, 2013). As such, quantifying possible variations can minimize the risk of iatrogenic injury during fracture fixation (de Souza Fernandes *et al.*, 2010a; Cassetta *et al.*, 2013a). The methodology employed to describe the internal morphology of the interforaminal region of the mandible, is an adaptation to that described by de Souza Fernandez (2010a). Bone quantity was assessed at three possible locations for mini-plate fixation. In contrast to other studies (Al-Jandan *et al*., 2013; Talaat *et al.*, 2015) in which bone quantity was measured directly anterior to the MC and roots of teeth, assessment of bone quality using the MF as a reference (de Souza Fernandes *et al.*, 2010) enabled the investigators to assess the possibility of a space with minimal risk of injury to tooth roots, the MC and AMF.

During mini-plate placement, a BCP thickness of 3 mm is sufficient to buttress screws and ensure stability of a fracture (Champy *et al*., 1978); however, recent studies show that BCP is thinner in the interforaminal region (de Souza Fernandes *et al.*, 2010a; Al-Jandan *et al.*, 2013; Talaat *et al.*, 2015), and is greater in males when compared to females (Cassetta *et al.*, 2013a; Momin, Kurabayashi & Yosue, 2013). The sex trend was also observed in the current investigation at selected sites on foraminal and inferior transverse planes, and ancestral differences between males were observed at selected sites.

In our cohort, the degree of tooth loss showed a weak negative association with BCP at most sites. More sites on the superior plane showed this association bilaterally, compared to sites on the foraminal and inferior transverse planes. This weak association could be attributed to low occlusal contact between teeth in the maxillary and mandibular arches, as was observed by Oettlé (2014). In contrast to the present study, Katranji and colleagues (2007) reported a greater BCP in apical regions of edentulous mandibles compared to the same regions in fully dentate mandibles.

Bone resorption becomes pronounced with time (Ozan *et al.*, 2013). Our findings showed a weak negative association between age and BCP thickness, particularly at sites mesial to the MF on superior and inferior transverse planes of right hemi-mandibles. These findings suggest that age leads to structural changes independent to tooth loss. The sidedness regarding the influence of age on BCP seen in the present study, have not been observed in other investigations.

The course of the MC and awareness of ALs are crucial when planning surgical interventions (Katranji, Misch & Wang, 2007; Al-Jandan *et al.*, 2013; Talaat *et al.*, 2015). Our findings revealed that out of 18 (16.88%) right and 16 (15.09%) left canals observed in hemi-mandibles, three ALs had associations with foraminal transverse planes (2.82%), while seven ALs were associated with inferior transverse planes, bilaterally (6.57%). Sex differences regarding the prevalence of ALs, have been reported previously (Momin, Kurabayashi & Yosue, 2013; Patterson, 2014; Kheir & Sheikhi, 2017); however, in the current investigation, sex differences were only observed regarding the location of MCs. The MCs of left hemi-mandibles were lower and more anterior in SAC males when compared to SAC females at 4.5 mm lateral to the foraminal midpoint. The course of the MC showed no difference between ancestral groups, dentition nor age.

The availability of cancellous bone not only provides resistance during the drilling process for screw anchorage, but can aid screw buttressing (Rahpeyma & Khajehahmadi, 2018). In addition, it is quantified preoperatively to determine the risk for injury to vital structures (Katranji, Misch & Wang, 2007). While earlier studies have advocated the use of mono-cortical screws with standard lengths of 5–7 mm for mini-plate placement (Heidemann & Gerlach, 1999; Saka, 2000), recent studies have indicated a high risk for injury to the IAN with mono-cortical screws of these lengths (de Souza Fernandes *et al.*, 2010a; Al-Jandan *et al.*, 2013; Talaat *et al.*, 2015). Our findings showed that the predicted risk for iatrogenic injury to teeth on the superior transverse plane of mandibles containing dentition ranged between 20.25 - 25.32% for right and 12.5 - 13.75% for left hemi-mandibles with screws of these lengths. De Souza Fernandez and colleagues (2010a) conducted an investigation on this plane of 1.25 mm superior to the foraminal midpoint because the distance is half the breadth of the notches between the holes of a mini-plate, and demarcates the lowest point for mini-plate placement. Despite this, their findings showed that the superior transverse plane had association with teeth in up to 62.5% of cases. The risk for injury to tooth roots can be reduced by utilizing interradicular septa for screw anchorage (de Souza Fernandes *et al.*, 2010b).

Our findings revealed that buccal bone was thickest on the foraminal transverse plane compared to superior and inferior transverse planes. The predicted risk for iatrogenic injury to the MC with 5 - 7 mm screws was low on this plane and ranged from 3.74 - 7.48% for right and 5.66 - 7.55% for left hemi-mandibles. A similar trend regarding thicker bone on this plane was noted by de Souza Fernandez (2010a), although their findings indicating no risk for injuries, irrespective of screw length. On the inferior transverse plane, the predicted risk for injury to the MC with 5 - 7 mm screws ranged between 9.35 - 20.56% in right and 11.32 - 33.02% in left hemi-mandibles. The higher risk of injury to the MC on this plane of left hemi-mandibles, is linked to sex differences in the course of the MC. Although buccal bone was thinner in males, the 11.32% risk for injury was associated with MCs of SAC females. Hemi-mandibles had a low risk for injury to AMF, with only 1 right AMF (0.93%) housed within a 1 mm radius of a screw insertion point and an additional 2 left AMF (1.87%) in close relation to mini-plate placement locations.

CHAPTER SEVEN: CONCLUSION

This study demonstrates how sex, ancestry, age and dentition influences internal and external morphological variations in the interforaminal region, and how these variations may influence risk for iatrogenic injuries during mini-plate fixation. To our knowledge, this is the first study of its kind to investigate internal and external morphological variations in this region.

Our results revealed that the position of the MF in in relation to teeth is not influenced by sex and ancestry. Our findings also indicated clear sex differences in the external morphology of the mandible that could aid in localizing the MF and improve outcomes for fracture fixation. An ancestral difference was only observed between right hemi-mandibles of SAC and SAB males. The influence of tooth loss and age on the external morphology did not vary between sex and ancestral subgroups but influenced the vertical height of the mandible. The thickness of the BCP was influenced by age, dentition, sex and ancestry. However, buccal bone was only affected by sex, particularly on the inferior transverse plane of left hemi-mandibles.

These findings suggest that knowledge of sex differences can aid in localizing the MF as well as choosing the appropriate screw length to prevent inadvertent injury to the MC. Further investigation on a larger sample including SAB and SAW females, is warranted to ascertain whether ancestral differences exists between female South Africans. Our findings also indicate that, apart from dentition, variables such as sex, age and dentition need not be considered for mini-plate placement on the superior transverse plane, and that sex differences should only be considered when mini-plate placement is performed on the inferior transverse plane. The foraminal plane carries low risks for iatrogenic injuriesand showed no associations with any variables. This study therefore concludes that a subgroup-specific approach is not warranted when treating interforaminal fractures.

Limitations and future studies

The cohort was limited by the availability of cadavers. For this reason, hemi-mandibles of known ancestry, sex and age were included in the investigation regardless of the degree of dentition. As a result, hemi-mandibles showed great variability in the distribution of teeth. The absence of each tooth influenced the height of the mandible superior to the MF to a different degree. However, the influence of tooth loss on external mandibular morphology could not be fully elucidated because the presence and distribution of maxillary teeth of cadavers from which mandibles were retrieved, were unknown. During the statistical analysis of the influence of dentition on the internal morphology, the total number of teeth per hemi-mandible was correlated with parameter values, this was deemed more viable as opposed to treating each tooth as a variable. Future studies investigating the influence of tooth loss on mandibular form should therefore note the occlusion between maxillary and mandibular teeth and define dentition subgroups according to locations of the mandible where teeth are in occlusion.

This study quantified the thickness of the buccal bone to assess the degree to which screws can surpass the BCP without injuring vital structures. However, many of the mandibles in this investigation had sparsely distributed cancellous bone which would increase the risk for screw loosening following mini-plate placement in mandibles with a thin BCP. Future studies should therefore assess the density of CAB and COB in the South African population.

When describing variations of nerve extensions mesial to the MF, it was assumed that observed extensions were ALs; however, the possibility exists that the observed structures were mandibular incisive canals. Future studies are needed to ascertain the prevalence and mean lengths of ALs and mandibular incisive canals in South Africans.

To minimize the costs in this investigation, a pencil was used to demarcate the locations for mandible transection and a hand drill was used to transect the mandible. These materials were not ideal for obtaining precise bone segments, especially in mandibles containing teeth. Future studies should ideally be performed on CBCT to obtain more accurate results. If CBCT analysis is not viable, investigations employing dry bone morphometric analysis should remove all teeth from mandibles prior to its transection, using a bone saw. A pencil was also used to draw the transverse planes for internal morphological investigation; however, given the size of most parameters measured, this methodology could have hampered accurate results.

Perhaps the greatest limitation of this study is that the diameter of mono-cortical screws was not considered when assessing bone quantity at the locations demarcated for screw anchorage. The risk for injury to tooth roots and the MC may therefore be underreported. Thus, when calculating the risk for injury to these structures, future studies should demarcate 2 mm thick transverse planes on the sagittal aspects of bone segments and record the frequency of structures in association with these planes.

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ADDENDA

Addendum A: Materials

Table 1: Materials used in study

Materials	Company
Dremel® 4000 multitool kit	Builder's Warehouse (Pty) Ltd. Parow Valley, Western Cape
Dremel® cutting discs	Builder's Warehouse (Pty) Ltd. Parow Valley, Western Cape
Moirs® food colouring (40 ml)	-
23 gage needles	Clicks. Ltd. Bellville, Western Cape
VFlex™ Health Care Particulate Respirator and Surgical mask	3M™. Rivonia, Gauteng
Kimix rubber latex (1L)	Kimix: Chemical and Lab supplies (Pty)Ltd Airport Industria, Western Cape
Mastercraft™ Digital vernier calliper (GS5071522)	Builder's Warehouse (Pty) Ltd. Parow Valley, Western Cape
50 ml syringes	-
Cotton balls	-
25% Ammonia solution	Merck Chemicals. (Pty) Ltd. Wadeville. Gauteng
Glacial Acetic acid	Merck- Cas: 10005706
Latex gloves	-

Addendum B: Observer reliability

Table 2: Positions of the mental foramen in the longitudinal axes of teeth

side	Observer	Kappa	Sig.
R	inter	.320	.100
	intra	.730	<. 001
L	inter	0.71	< .001
	intra	1	< .001

Table 3: Observer repeatability on the location and size of the mental foramen

side	Observer	SM-MF		MF(MAX)		AC-MF		MF(MIN)		MF-IM	
		r	Sig.	r	Sig.	R	Sig.	r	Sig.	r	Sig.
R	inter	.710	.030	.720*	.090*	.950	<.001	.630*	.070*	.680	.013
	Intra	.980	<.001	.940	<.001	.970	<.001	.770	.001	.970	<.001
L	Inter	.900	<.001	.830	<.001	.960	<.001	.850	<.001	.880	<.001
	Intra	.990	<.001	.940	<.001	.970	<.001	.760	.020	.970	<.001

Non-significant reliability is marked by an asterisk (*)

Table 4: Reliability scores for buccal cortical plate thickness

plane	Side	Observer	m		m2		l1		l2	
			r	Sig.	r	Sig.	R	Sig.	r	Sig.
S	R	Inter	1	< .001	.851	.002	.855	.002	.938	.002
		Intra	1	< .001	1	< .001	.943	< .001	.962	< .001
	L	Inter	.993	< .001	.831	.003	.964	< .001	.969	< .001
		Intra	.970	< .001	.946	< .001	.971	< .001	.966	< .001
F	R	Inter	.934	< .001	.924	< .001	.936	< .001	.901	< .001
		Intra	.977	< .001	.982	< .001	.933	< .001	.993	< .001
	L	Inter	.930	< .001	.976	< .001	.922	< .001	.867	< .001
		Intra	.994	< .001	.916	< .001	.991	< .001	.909	< .001
I	R	Inter	.963	< .001	.846	.002	.929	< .001	.913	< .001
		Intra	.986	< .001	.912	< .001	.988	< .001	.981	< .001
	L	Inter	.814	.005	.838	.003	.837	.003	.783	.009
		Intra	.974	< .001	.926	< .001	.967	< .001	.973	< .001

Table 5: Inter- and intra-observer reliability scores for buccal bone thickness

plane	Side	Observer	M		m2		l1		l2	
			r	Sig.	r	Sig.	R	Sig.	r	Sig.
S	R	Inter	.393*	.290*	.979	.000	.953	.000	.688	.033
		Intra	.961	.000	.984	.000	.999	.000	.968	.000
	L	Inter	.838	.003	.988	.000	.966	.000	.984	.000
		Intra	.241*	.328*	.984	.000	.963	.000	.997	.000
F	R	Inter	.959	.000	.832	.003	.818	.004	.946	.000
		Intra	.995	.000	.977	.000	.972	.000	.901	.000
	L	Inter	.960	.000	.910	.000	.986	.000	.963	.000
		Intra	.933	.000	.928	.000	.994	.000	.970	.000
I	R	Inter	.902	.000	.896	.000	.961	.000	.989	.000
		Intra	.990	.000	.998	.000	.972	.000	.970	.000
	L	Inter	.973	.000	.975	.000	.985	.000	.981	.000
		Intra	.971	.000	.991	.000	.985	.000	.995	.000

Non-significance is marked by (*)

Addendum C: Inferosuperior location of anterior loops and mandibular canals

Table 6: Frequency distribution of the inferosuperior location of canals relative to transverse planes.

	Anterior loops		Mandibular canals	
	ml	m2	l1	l2
Right				
Between plane S and F	-	-	-	-
Bisected by plane F	1 (0.93%)	3 (2.80%)	11 (10.28%)	8 (7.48%)
Between plane F and I	3 (2.80%)	6 (5.61%)	28 (26.2%)	22 (24.3%)
Bisected by plane I	2 (1.87%)	7 (6.54%)	31 (28.97%)	27 (25.2%)
Below plane I	2 (1.87%)	2 (1.87%)	38 (35.51%)	46 (43.0%)
Total	7 (6.54%)	18 (16.82%)	107 (100%)	107 (100%)
Left				
Between plane S and F	1 (0.94%)	1 (0.94%)	1 (0.94%)	2 (1.88%)
Bisected by plane F	1 (0.94%)	3 (2.83%)	7 (6.6%)	7 (6.6%)
Between plane F and I	-	2 (1.89%)	21 (19.8%)	16 (15.1%)
Bisected by plane I	3 (2.83%)	7 (5.6%)	37 (34.9%)	31 (29.25%)
Below plane I	1 (0.94%)	3 (2.83%)	40 (37.7%)	50 (47.2%)
Total	6(5.66%)	17 (16.04%)	106 (100%)	106 (100%)

Addendum D: Location of canals

Table 7: Inferosuperior and anteroposterior location of canals mesial and lateral to the foraminal midpoint. Significant differences were observed between SAC males and females at select sites lateral to the foraminal midpoint. Data (in mm) is expressed as mean ± standard deviation (SD)

	Site	SAC Female	SAC Male	SAW Male	SAB Male	Cohort
Right						
S-MC	m1	5.01 ± 1.89	5.20 ± 2.23	3.72 ± 0.41	4.91	4.74 ± 1.96
	m2	4.84 ± 3.32	6.39 ± 3.34	3.69 ± 0.12	4.38 ± 2.00	5.15 ± 2.46
	l1	5.14 ± 1.66	5.34 ± 1.71	6.00 ± 2.04	5.18 ± 1.47	5.39 ± 1.74
	l2	5.33 ± 1.67	5.55 ± 1.97	6.41 ± 1.90	5.94 ± 1.83	5.71 ± 1.88
BCP-MC	m1	2.86 ± 2.23	3.85 ± 0.94	3.45 ± 0.20	4.52	3.53 ± 1.38
	m2	1.72 ± 0.14	4.16 ± 1.96	3.98 ± 1.51	2.25 ± 1.57	3.42 ± 1.53
	l1	3.81 ± 1.16[a]	4.50 ± 1.10[b]	4.10 ± 1.02	4.95 ± 1.05	4.32 ± 1.15
	l2	4.25 ± 1.35[a]	5.08 ± 1.3[b]	4.68 ± 1.41	5.63 ± 1.39	4.86 ± 1.42
Left						
S-MC	m1	6.05 ± 2.07	5.55 ± 1.80	2.83	4.14 ± 1.66	5.01 ± 2.09
	m2	6.24 ± 1.36	6.45	1.92 ± 0.32	4.23 ± 1.77	5.03 ± 1.76
	l1	5.06 ± 1.36[a]	5.70 ± 1.81[b]	6.48 ± 1.61	5.42 ± 1.75	5.62 ± 1.70
	l2	5.11 ± 1.17	6.95 ± 1.78	6.77 ± 1.79	5.86 ± 1.62	5.86 ± 1.81
BCP-MC	m1	4.72 ± 1.60	0.25 ± 1.00	2.21	3.34 ± 0.69	3.89 ± 1.35
	m2	4.76 ± 0.69	5.03	2.38 ± 0.97	2.98 ± 1.77	3.65 ± 1.24
	l1	3.87 ± 1.06[a]	3.67 ± 0.97[b]	4.16 ± 1.16	4.92 ± 1.14	4.36 ± 1.19
	l2	4.52 ± 1.15	5.13 ± 1.55	4.69 ± 1.42	5.94 ± 1.00	4.99 ± 1.42

Differing letters a and b indicate significant differences between SAC males and females. Differing letters c and d indicate significant differences between two male subgroups. Significance was defined at $p < .050$. (S) transverse plane 3 mm superior to the foraminal plane. (MC) canal. (BCP) buccal cortical plate. (m1) 4.5 mm mesial to the foraminal midpoint. (m2) 9 mm mesial to the foraminal midpoint. (l1) 4.5 mm lateral to the foraminal midpoint. (l2) 9 mm lateral to the foraminal midpoint. (S-MC) inferosuperior location of the canal with reference to the superior transverse plane. (SAC) South African Coloured, (SAW) South African White, (SAB) South African Black

Addendum E: Minimum bone thickness and risks for iatrogenic injury

Table 8: Risk for iatrogenic injury. The risk for injury is lowest on the inferior transverse plane

Screw length (mm)	**MBB cum.freq (mm)**	**Risk for iatrogenic injury on transverse planes**		
		Plane S	**Plane F**	**Plane I**
Right				
4	≥ 2.99	16 (20.25%)	2 (1.87%)	2 (1.87%)
5	≥ 3.99	20 (25.32%)	4 (3.74%)	10 (9.35%)
6	≥ 4.99	20 (25.32%)	6 (5.61%)	16 (14.95%)
7	≥ 5.99	20 (25.32%)	8 (7.48%)	22 (20.56%)
8	≥ 6.99	20 (25.32%)	8 (7.48%)	29 (27.10%)
9	≥ 7.99	20 (25.32%)	14 (13.08%)	33 (30.84%)
≥10	≥ 8.99	21 (26.58%)	16 (14.95%)	37 (34.58%)
Left				
4	≥ 2.99	7 (8.75%)	2 (1.89%)	5 (4.72%)
5	≥ 3.99	10 (12.5%)	6 (5.66%)	12 (11.32%)
6	≥ 4.99	11(13.75%)	7 (6.60%)	24 (22.64%)
7	≥ 5.99	11(13.75%)	8 (7.55%)	35 (33.02%)
8	≥ 6.99	11(13.75%)	8 (7.55%)	45 (42.45%)
9	≥ 7.99	11(13.75%)	8 (7.55%)	47 (44.34%)
≥10	≥ 8.99	12 (15%)	9 (8.49%)	45 (45.28%)

(S) Plane 3 mm superior to the foraminal plane, (F) plane bisecting the horizontal foraminal midpoint, (I) plane 3 mm inferior to the foraminal plane. (Cum.freq) Cumulative frequency, (MBB) minimum buccal bone ameliorate

Addendum F: Plagiarism report

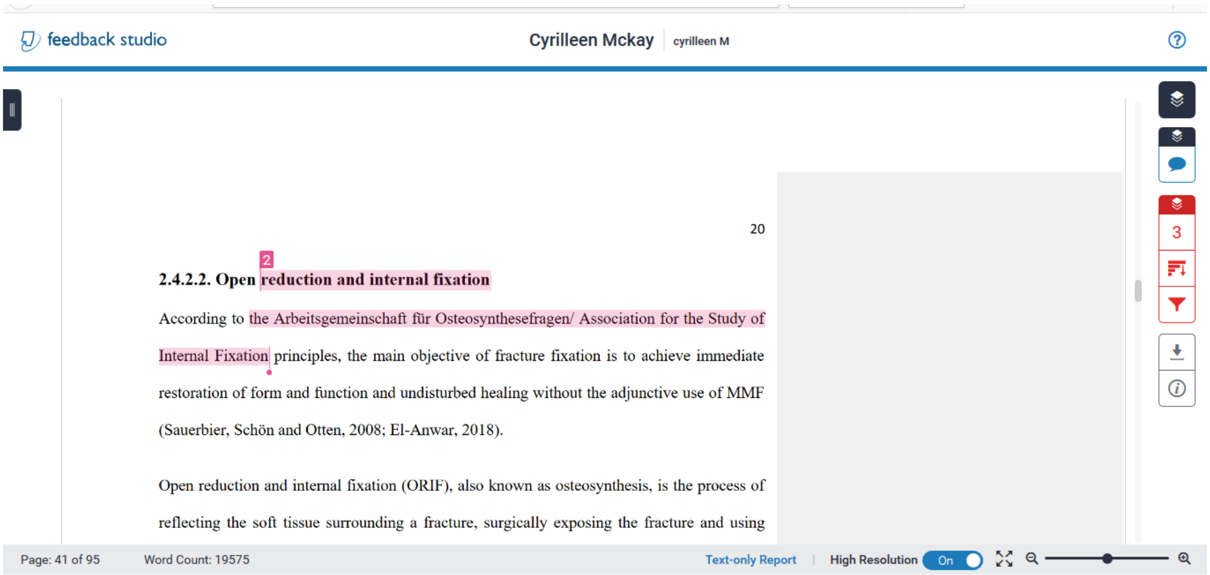

Figure 1: Plagiarism report